

# AS5048A/AS5048B

## Magnetic Rotary Encoder (14-Bit Angular Position Sensor)

### General Description

The AS5048 is an easy to use 360° angle position sensor with a 14-bit high resolution output.

The IC measures the absolute position of the magnet's rotation angle and consists of Hall sensors, analog digital converter and digital signal processing. The absolute position information of the magnet is directly accessible over a PWM output and can be read out over a standard SPI or a high speed I<sup>2</sup>C interface. AS5048A has a SPI interface, AS5048B I<sup>2</sup>C interface. Both devices offer a PWM output.

The zero position can be programmed via SPI or I<sup>2</sup>C command. This simplifies the assembly of the complete system because the zero position of the magnet does not need to be mechanically aligned. The sensor tolerates misalignment, air gap variations, temperature variations and as well external magnetic fields. This robustness and wide temperature range (-40°C up to 150°C) of the AS5048 makes the IC ideal for rotation angle sensing in harsh industrial and medical environments. Several AS5048 ICs can be connected in daisy chain for serial data read out. An internal voltage regulator allows the AS5048 to operate at either 3.3V or 5V supplies.

*Ordering Information and Content Guide appear at end of datasheet.*

### Key Benefits & Features

The benefits and features of AS5048A/AS5048B, Magnetic Rotary Encoder (14-Bit Angular Position Sensor) are listed below:

**Figure 1:**  
**Added Value of Using AS5048**

| Benefits                            | Features   |
|-------------------------------------|--|
| • No external programmer needed     | • Standard SPI or I <sup>2</sup> C interface and PWM     |
| • High precision                    | • 14-bit resolution (0.0219°/LSB)                        |
| • Easy to use                       | • Zero position programmable via SPI or I <sup>2</sup> C |
| • Low material costs (no shielding) | • Immune to external magnetic stray fields               |

- Contactless rotary position sensor over 360°
- Temperature range: -40°C to 150°C
- 3.3V / 5V compliant
- Package: 14-pin TSSOP (5 x 6.4mm)

## Applications

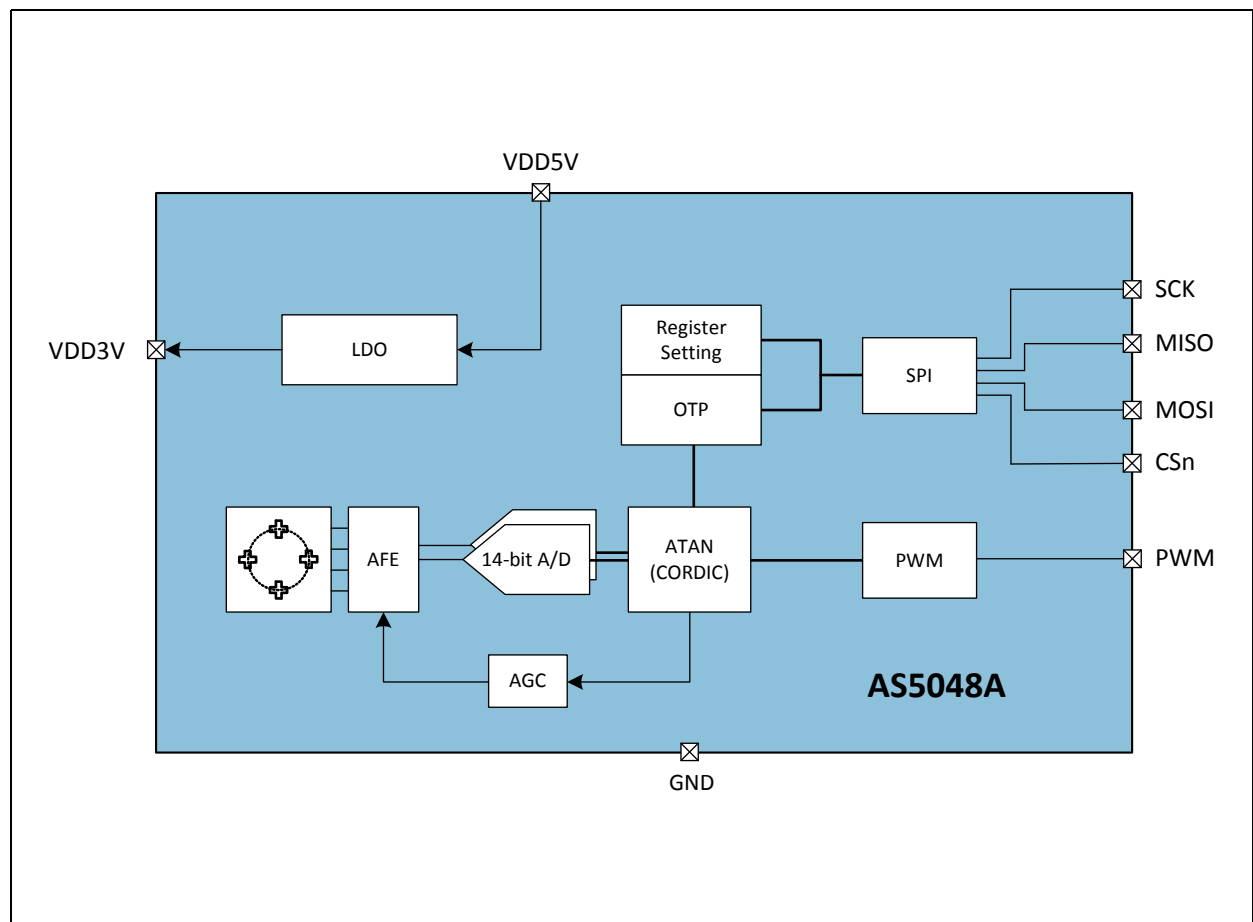
The applications of AS5048 include:

- Robotic joint position detection
- Industrial motor position control
- Medical robots and fitness equipment

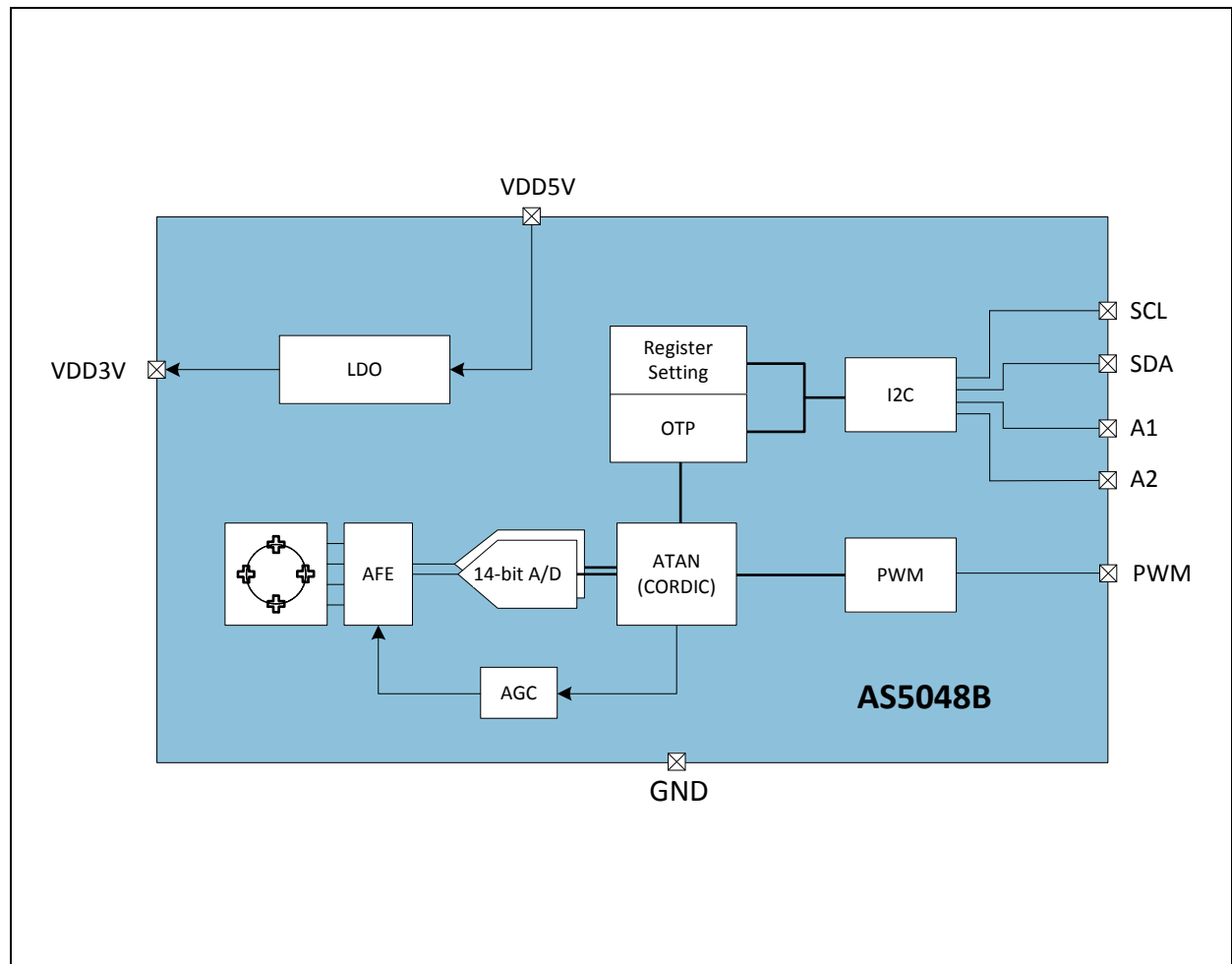
## Block Diagram

The functional blocks of this device are shown below:

**Figure 2:**  
**AS5048A Block Diagram**



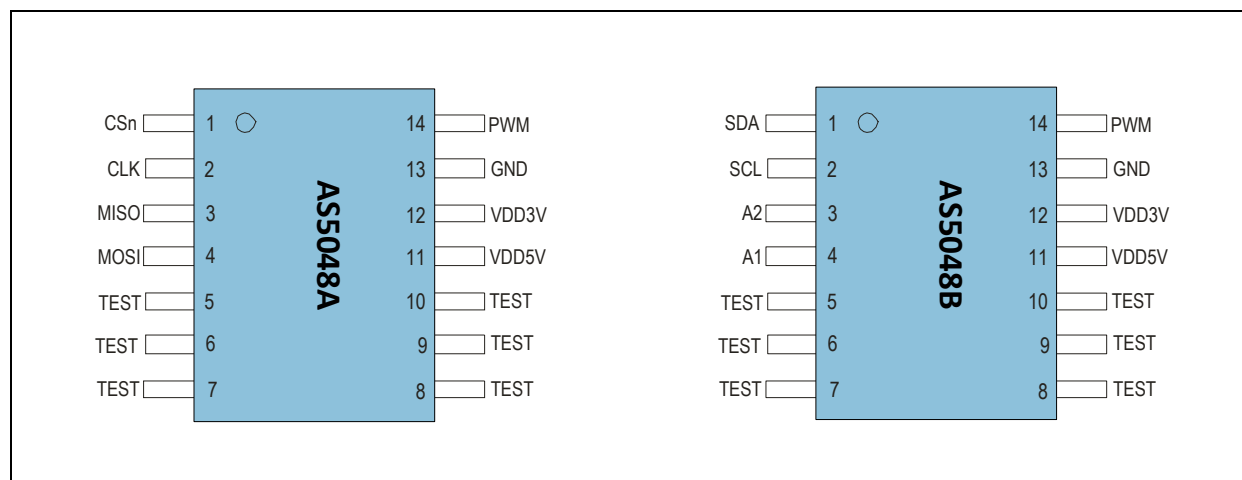
**Figure 3:**  
**AS5048B Block Diagram**



## Pin Assignments

The AS5048A/AS5048B pin assignments are described below.

**Figure 4:**  
TSSOP14 Pin Configurations



**Figure 5:**  
TSSOP14 Pin Descriptions for AS5048A

| Pin | AS5048A | Pin Type   | Description   |
|-----|---------|--|---|
| 1   | CSn     | Digital input with Schmitt trigger                 | SPI chip select - active low  |
| 2   | CLK     |  | SPI clock input   |
| 3   | MISO    | Digital I/O with Schmitt trigger in the input path | SPI master in/slave out   |
| 4   | MOSI    | Digital input with Schmitt trigger                 | SPI master out/slave in   |
| 5   | TEST    | Analog I/O   | Test pin should be connected to GND.  |
| 6   | TEST    | Analog I/O   | Test pins should be left open during normal operation.  |
| 7   | TEST    |  |   |
| 8   | TEST    |  |   |
| 9   | TEST    |  |   |
| 10  | TEST    |  |   |
| 11  | VDD5V   | Supply pad   | Positive Supply Voltage, 3.0 to 5.5 V   |
| 12  | VDD3V   |  | 3.3V Regulator output; internally regulated from VDD. Connect to VDD for 3V supply voltage. 10µF capacitor to GND required in 5V operation mode |
| 13  | GND     |  | Negative Supply Voltage (GND)   |
| 14  | PWM     |  | Pulse Width Modulation output   |

**Figure 6:**  
**TSSOP14 Pin Description for AS5048B**

| Pin | AS5048B | Type                               | Description   |
|-----|---------|------------------------------------|---|
| 1   | SDA     | Digital I/O with open drain output | Data pin I <sup>2</sup> C interface   |
| 2   | SCL     | Digital input with Schmitt trigger | I <sup>2</sup> C clock input  |
| 3   | A2      |                                    | I <sup>2</sup> C address selection pin 3  |
| 4   | A1      |                                    | I <sup>2</sup> C address selection pin 4  |
| 5   | TEST    | Analog I/O                         | Test pin should be connected to GND.  |
| 6   | TEST    | Analog I/O                         | Test pins should be left open during normal operation.  |
| 7   | TEST    |                                    |   |
| 8   | TEST    |                                    |   |
| 9   | TEST    |                                    |   |
| 10  | TEST    |                                    |   |
| 11  | VDD5V   | Supply pad                         | Positive Supply Voltage, 3.0 to 5.5 V   |
| 12  | VDD3V   |                                    | 3.3V Regulator output; internally regulated from VDD. Connect to VDD for 3V supply voltage. 10µF capacitor to GND required in 5V operation mode |
| 13  | GND     |                                    | Negative Supply Voltage (GND)   |
| 14  | PWM     | Digital output – push-pull         | Pulse Width Modulation output   |

## Absolute Maximum Ratings

Stresses beyond those listed under [Absolute Maximum Ratings](#) may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated under [Operating Conditions](#) is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

**Figure 7:**  
**Absolute Maximum Ratings**

| Symbol                                    | Parameter  | Min  | Max     | Unit | Note  |
|---|--|------|---------|------|---|
| Electrical Parameters                     |  |      |         |      |   |
| VDD5V                                     | DC supply voltage at VDD pin                       | -0.3 | 7       | V    |   |
| VDD3V                                     | DC voltage at VDD3V pin                            | -0.3 | 5       | V    |   |
| GND                                       | DC voltage at GND pin                              | -0.3 | 0.3     | V    |   |
| V <sub>IN</sub>                           | Input pin voltage                                  |      | VDD+0.3 | V    |   |
| I <sub>SCR</sub>                          | Input current (latchup immunity)                   | -100 | 100     | mA   | Jedec 78  |
| Electrostatic Discharge                   |  |      |         |      |   |
| ESD                                       | Electrostatic discharge                            | ± 2  |         | kV   | MIL 883 E method 3015   |
| Power Dissipation                         |  |      |         |      |   |
| P <sub>T</sub>                            | Total power dissipation (all supplies and outputs) |      | 150     | mW   |   |
| Temperature Ranges and Storage Conditions |  |      |         |      |   |
| T <sub>STRG</sub>                         | Storage temperature                                | -55  | 150     | °C   |   |
| T <sub>BODY</sub>                         | Package body temperature                           |      | 260     | °C   | The reflow peak soldering temperature (body temperature) specified is in accordance with IPC/JEDEC J-STD-020 “Moisture Solid State Surface Mount Devices”. The lead finish from Pb-free leaded packages is matte tin (100%Sn) |
| RH <sub>NC</sub>                          | Relative humidity non-condensing                   | 5    | 85      | %    |   |
| MSL                                       | Moisture sensitivity level                         | 3    |         |      | Represents a maximum floor life time of 168h  |

## Electrical Characteristics

All in this specification defined tolerances for external components need to be assured over the whole operation conditions range and also over lifetime.

## Operating Conditions

**Figure 8:**  
Operating Conditions

| Symbol           | Parameter                    | Min | Max | Unit | Note  |
|------------------|------------------------------|-----|-----|------|---|
| VDD5V            | Positive supply voltage      | 4.5 | 5.5 | V    | 5V Operation via LDO                                |
| VDD3V            |                              | 3   | 3.6 | V    | LDO output voltage                                  |
| VDDCORE          | Positive core supply voltage | 3   | 3.6 | V    |   |
| T <sub>AMB</sub> | Ambient temperature          | -40 | 150 | °C   | Only for 5V operation.<br>T_amb_max for 3V is 125°C |
| I <sub>SUP</sub> | Supply current               |     | 15  | mA   |   |

## DC/AC Characteristics for Digital Inputs and Outputs

**Figure 9:**  
DC/AC Characteristics

| Symbol   | Parameter                 | Min           | Max           | Unit |
|--|---------------------------|---------------|---------------|------|
| <b>CMOS Digital Input with Schmitt Trigger: CSn, CLK, MOSI and SCL, A1, A2</b> |                           |               |               |      |
| V <sub>IH</sub>  | High level input voltage  | 0.7 * VDDCORE |               | V    |
| V <sub>IL</sub>  | Low level input voltage   |               | 0.3 * VDDCORE | V    |
| I <sub>LEAK</sub>  | Input leakage current     |               | 1             | μA   |
| <b>CMOS Output: PWM, MISO, SDA</b>   |                           |               |               |      |
| V <sub>OH</sub>  | High level output voltage | VDDCORE - 0.5 |               | V    |
| V <sub>OL</sub>  | Low level output voltage  |               | GND+0.4       | V    |
| C <sub>L</sub>   | Capacitive load           |               | 50            | pF   |
| I <sub>OUT</sub>   | Output current            |               | 4             | mA   |

## Electrical System Specifications

VDD5V = 5V, T<sub>AMB</sub> = -40 to 150°C unless noted otherwise.

**Figure 10:**  
System Specification

| Symbol                      | Parameter   | Conditions  | Min   | Typ   | Max   | Unit |
|-----------------------------|---|---|-------|-------|-------|------|
| B <sub>z</sub>              | Magnetic input field  |   | 30    | 50    | 70    | mT   |
| f <sub>sample</sub>         | Output sampling rate  |   | 10.2  | 11.25 | 12.4  | kHz  |
| RES                         | Output resolution   |   | 14    |       |       | Bit  |
| Noise                       | Sensor output noise   | 2.73LSB@14bit, rms value  |       |       | 0.06  | deg  |
| t <sub>prop</sub>           | System propagation delay  |   | 90.7  | 100   | 110.2 | μs   |
| f <sub>PWM</sub>            | PWM frequency   |   | 0.907 | 1     | 1.102 | kHz  |
| INL <sub>OPT</sub><br>@25°C | Non-linearity, optimum placement of the magnet                                |   |       |       | ± 0.8 | deg  |
| INL <sub>OPT+TEMP</sub>     | Non-linearity optimum placement of the magnet over the full temperature range |   |       |       | ±1    | deg  |
| INL <sub>DIS+TEMP</sub>     | Non-linearity @ displacement of magnet and temperature -40°C to 150°C         | Assuming N35H magnet (D=8mm, H=3mm) 500μm displacement in x and y z-distance @ 2000μm |       |       | ±1.2  | deg  |
| t <sub>startup</sub>        | Startup time  |   |       |       | 10    | ms   |



## Functional Description

The AS5048 is a magnetic Hall sensor system manufactured in a CMOS process. A lateral Hall sensor array is used to measure the magnetic field components perpendicular to the surface of the chip. The AS5048 uses self-calibration methods to eliminate signal offset and sensitivity drifts.

The integrated Hall sensors are placed around the center of the device and deliver a voltage representation of the magnetic flux  $B_z$ .

Through Sigma-Delta Analog-to-Digital Converter (ADC) and Digital Signal-Processing (DSP) algorithms, the AS5048 provides accurate high-resolution absolute angular position information. This is executed by a Coordinate Rotation Digital Computer (CORDIC) which calculates the angle and the magnitude of the Hall array signals.

The DSP is also used to provide digital information at the outputs that indicate movements of the magnet towards or away from the device's surface, in the z-axis.

A small diametrically magnetized (two-pole) standard magnet provides the angular position information. Depending on the system requirements different magnet diameters are possible. Additional flexibility is given by the wide range of the magnetic input range. The AS5048 can be combined with NeFeB, SmCo and alternative magnet materials e.g. hard ferrites. The AS5048 provides a 14-bit binary code representing the angular position of the magnet. The type of output is pre-programmed as SPI version A or I<sup>2</sup>C version B. Simultaneously a PWM output signal is available in 12 bit format.

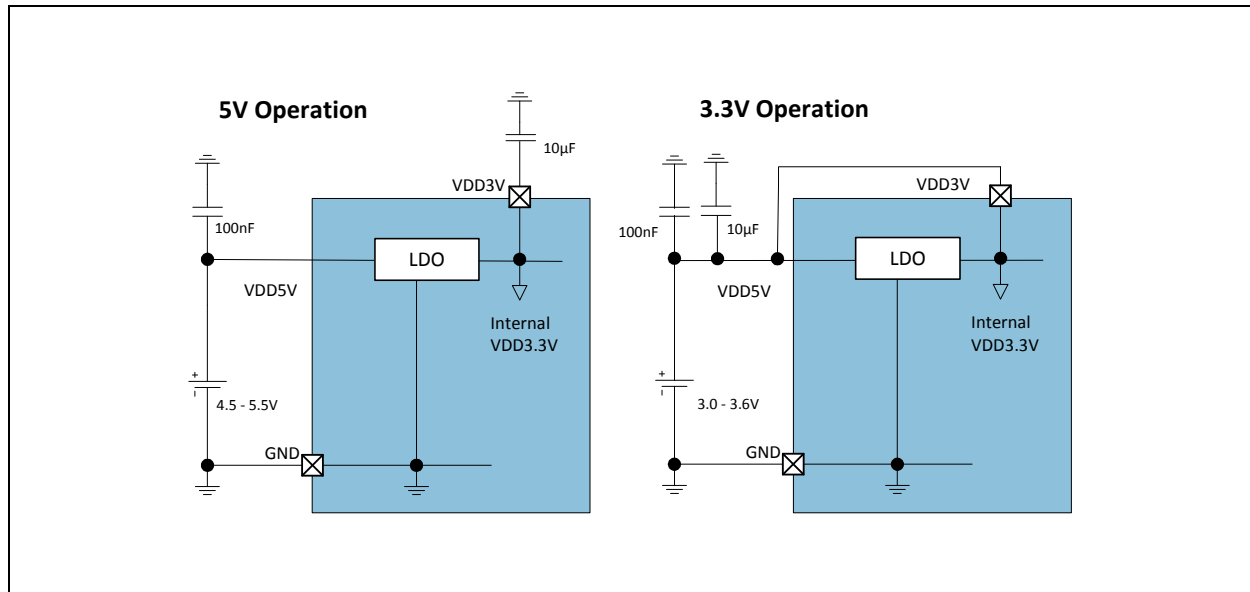
A simple programming of the zero position is possible over the interface. No additional programmer is needed. The AS5048 uses one time programmable (OTP) fuses for permanent programming of the user settings. The verification is possible over a simple digital readout of the OTP content.

## Operation

### Supply Voltage Configuration

The AS5048 operates at  $5V \pm 10\%$ , using an internal Low-Dropout (LDO) voltage regulator. In addition a 3.3V operation is possible. The **VDD3V** output is intended for internal use only. **It must not be loaded with an external load.**

**Figure 11:**  
Connections for 5V and 3.3V Supply Voltages



**Note(s):**

1. The pin **VDD3V** must always be buffered by a 10 µF capacitor in 5V operation. It must not be left floating, as this may cause unstable internal supply voltages which may lead to larger output jitter of the measured angle.  
In 3V operation the **VDD3V** must be shorted to **VDD5V**. The ambient temperature  $T_{AMB}$  is limited to 125°C in this mode.

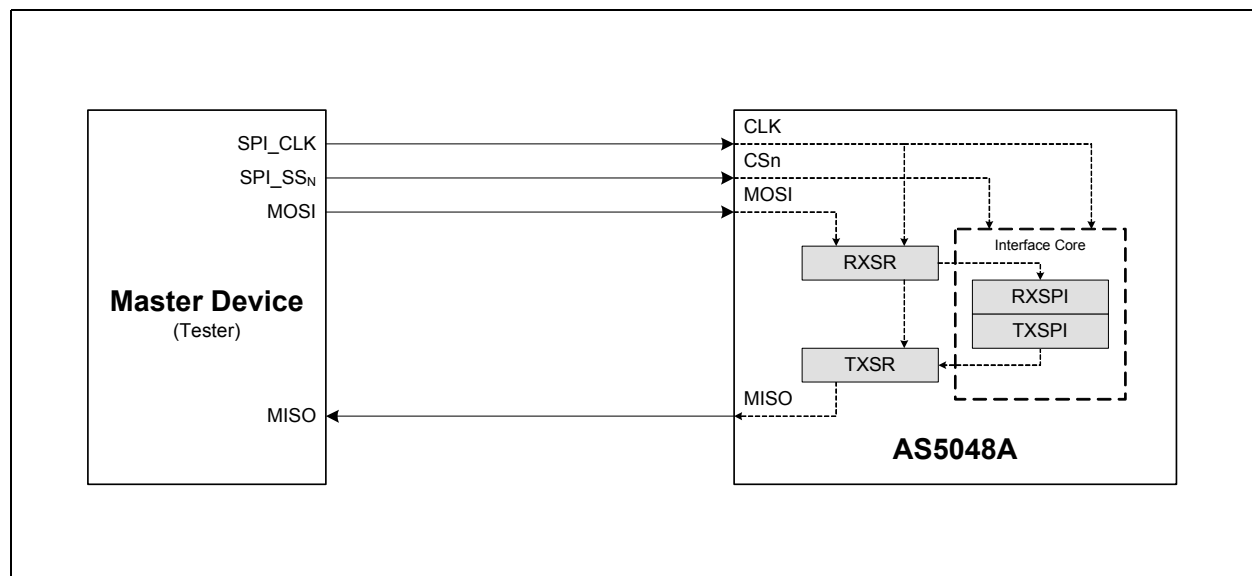
### SPI Interface

The 16 bit SPI Interface enables read / write access to the register blocks and is compatible to a standard micro controller interface. The SPI is active as soon as **CSn** is pulled low. The AS5048A then reads the digital value on the **MOSI** (master out slave in) input with every falling edge of **CLK** and writes on its **MISO** (master in slave out) output with the rising edge. After 16 clock cycles **CSn** has to be set back to a high status in order to reset some parts of the interface core.

#### **SPI Interface Signals (4-Wire Mode, Wire\_mode = 1)**

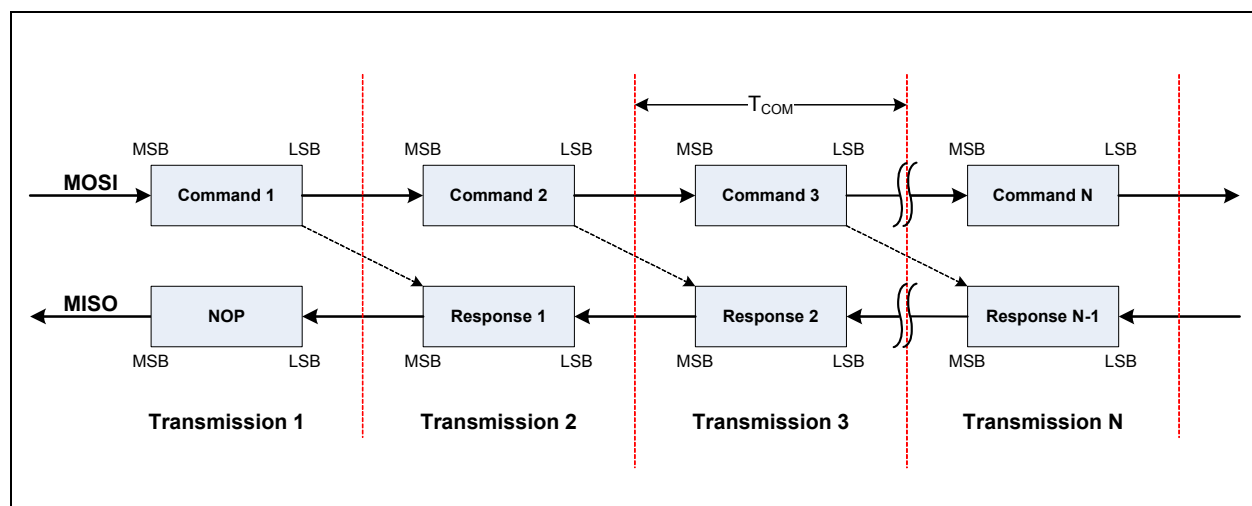
The AS5048A only supports slave operation mode. Therefore **CLK** for the communication as well as the **CSn** signal has to be provided by the test equipment. The following picture shows a basic interconnection diagram with one master and an AS5048A device and a principle schematic of the interface core.

**Figure 12:**  
**SPI Connection AS5048A with  $\mu$ C**



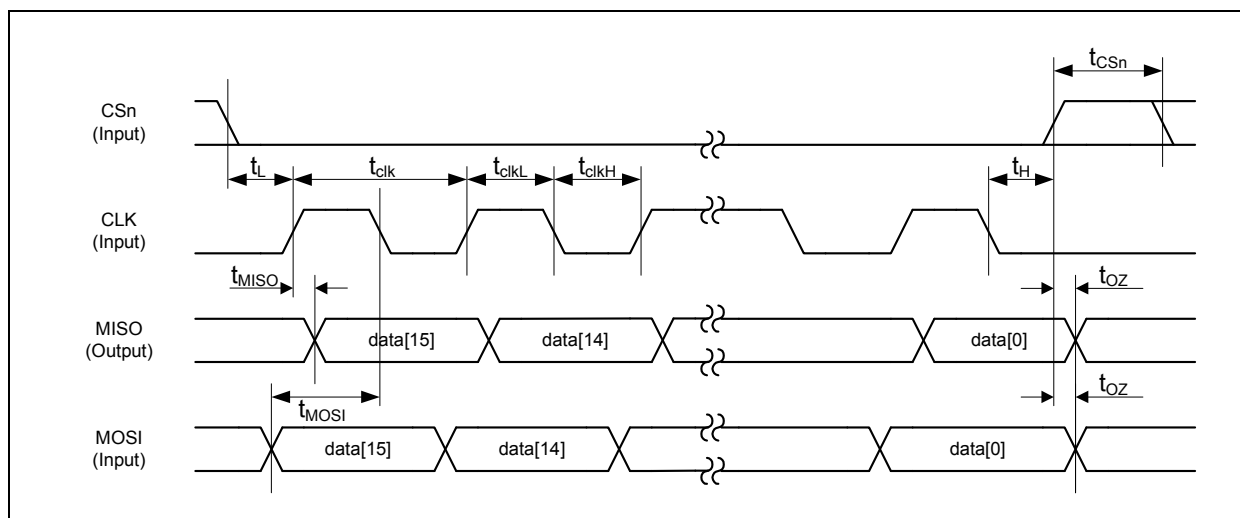
Because the interface has to decode the sent command before it can react and provide data the response of the chip to a specific command applied at a time T can be accessed in the next transmission cycle ending at  $T + T_{COM}$ . The data are sent and read with **MSB first**. Every time the chip is accessed it is sending and receiving data.

**Figure 13:**  
**SPI Command/Response Data Flow**



## SPI Timing

**Figure 14:**  
SPI Timing Diagram



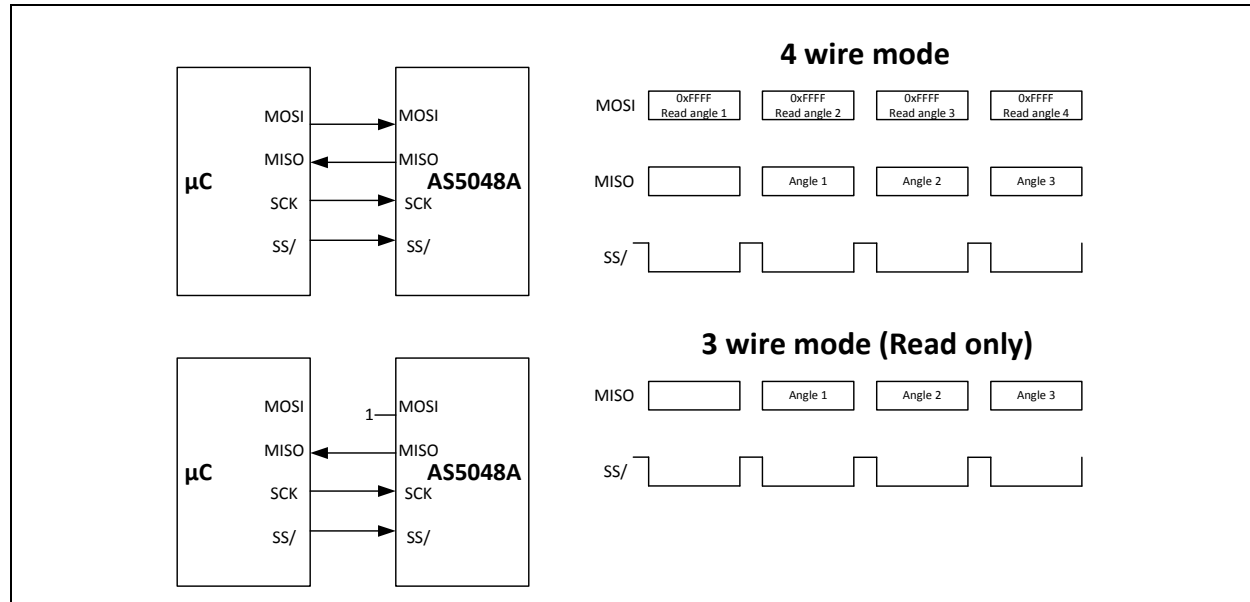
**Figure 15:**  
SPI Timing Characteristics

| Parameter  | Description  | Min | Max | Unit |
|------------|--|-----|-----|------|
| $t_L$      | Time between CSn falling edge and CLK rising edge            | 350 |     | ns   |
| $T_{CLK}$  | Serial clock period  | 100 |     | ns   |
| $t_{CLKL}$ | Low period of serial clock                                   | 50  |     | ns   |
| $t_{CLKH}$ | High period of serial clock                                  | 50  |     | ns   |
| $t_H$      | Time between last falling edge of CLK and rising edge of CSn | 50  |     | ns   |
| $T_{CSnH}$ | High time of CSn between two transmissions                   | 350 |     | ns   |
| $t_{MOSI}$ | Data input valid to clock edge                               | 20  |     | ns   |
| $t_{MISO}$ | CLK edge to data output valid                                |     | 20  | ns   |

## SPI Connection to the Host $\mu$ C

### Single Slave Mode

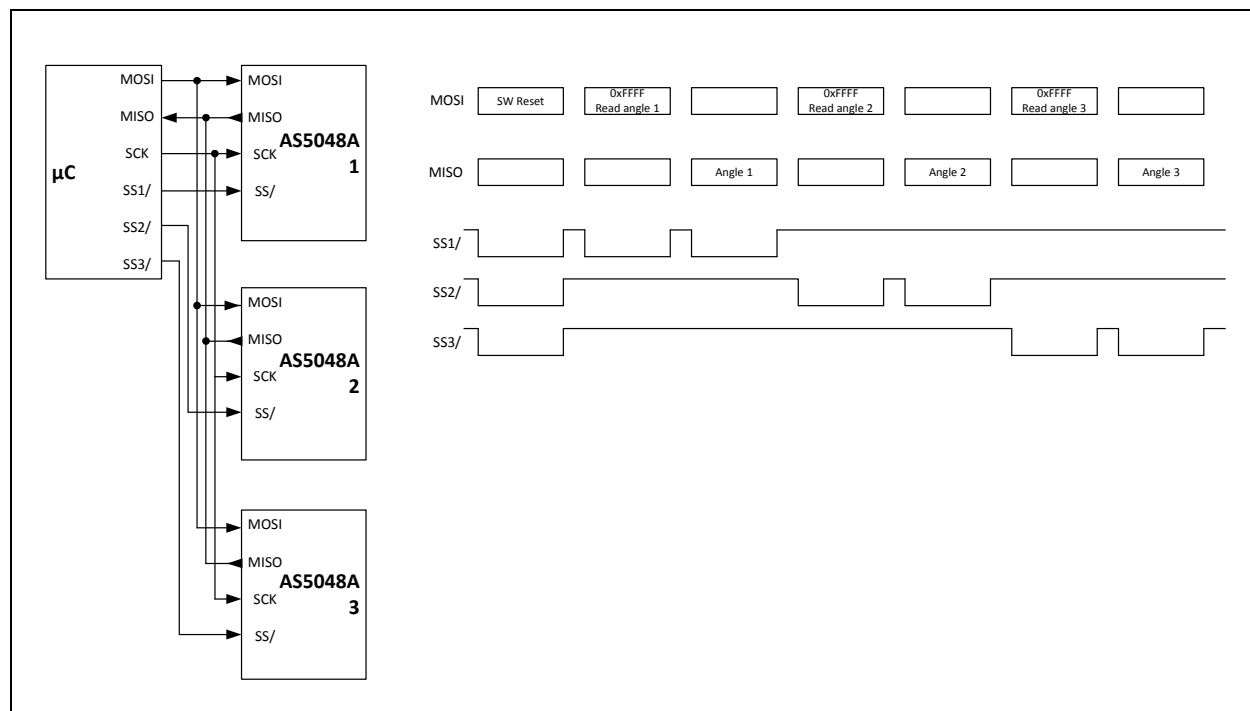
**Figure 16:**  
Single Slave Mode



**Single Slave Mode:** This figure shows the SPI connection to the host  $\mu$ C using Single Slave Mode.

### 3 Wire Mode (read only)

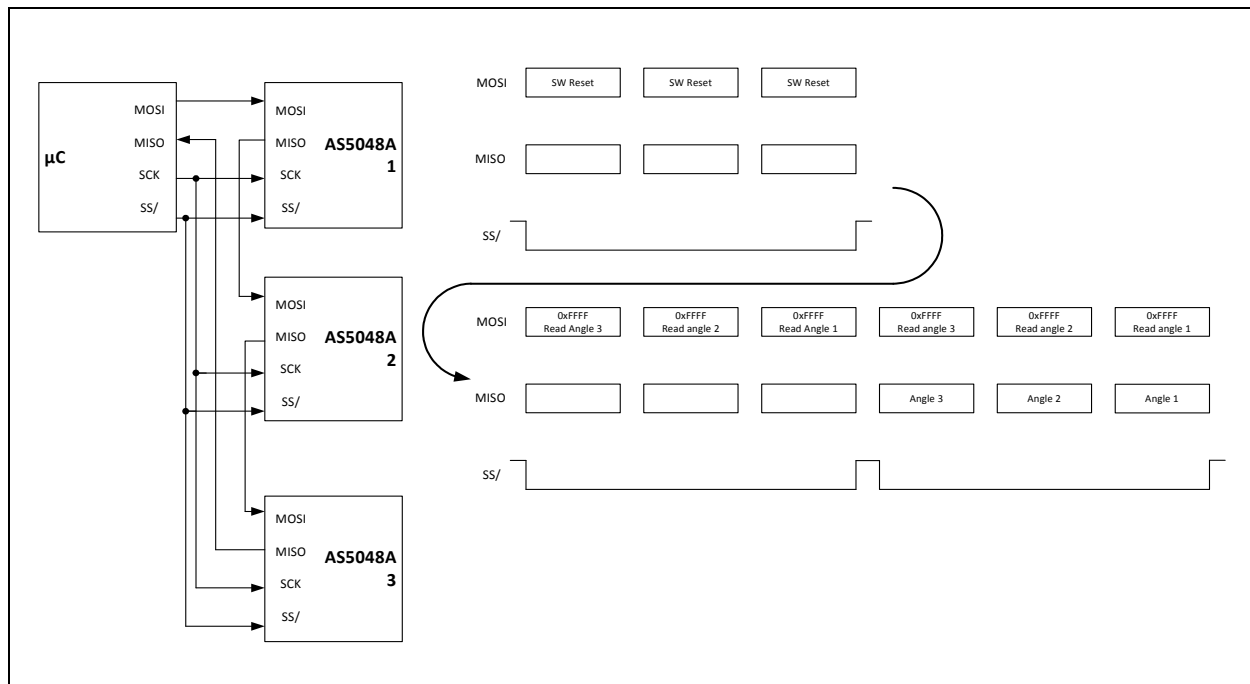
**Figure 17:**  
Multiple Slave, n+3 Wire (Separate ChipSelect)



**Multiple Slave, n+3 Wire (Separate ChipSelect):** This figure shows the SPI connection to the host  $\mu$ C using 3 Wire mode.

## Daisy Chain, 4 Wire

**Figure 18:**  
Daisy Chain, 4 Wire



**Daisy Chain, 4 Wire:** This figure shows the SPI connection to the host  $\mu$ C using Daisy Chain, 4 wire mode.

## SPI Communication Command Package

Every command sent to the AS5048A is represented with the following layout.

**Figure 19:**  
SPI Command Package

| Command Package              |     |                                       |               |    |    |    |   |   |   |   |   |   |   |   |   |     |
|------------------------------|-----|---------------------------------------|---------------|----|----|----|---|---|---|---|---|---|---|---|---|-----|
| Bit                          | MSB | 14                                    | 13            | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | LSB |
|                              | PAR | RWn                                   | Address<13:0> |    |    |    |   |   |   |   |   |   |   |   |   |     |
| Bit Definition & Description |     |                                       |               |    |    |    |   |   |   |   |   |   |   |   |   |     |
| PAR                          |     | Parity bit (EVEN)                     |               |    |    |    |   |   |   |   |   |   |   |   |   |     |
| RWn                          |     | Indicates read(1) or write(0) command |               |    |    |    |   |   |   |   |   |   |   |   |   |     |
| Address                      |     | 14 bit address code                   |               |    |    |    |   |   |   |   |   |   |   |   |   |     |

### Read Package (Value Read from AS5048A)

The read frame always contains two alarm bits, the parity and error flags and the addressed data of the previous read command.

**Figure 20:**  
SPI Read Package

| Read Package                 |     |  |            |    |    |    |   |   |   |   |   |   |   |   |   |     |
|------------------------------|-----|--|------------|----|----|----|---|---|---|---|---|---|---|---|---|-----|
| Bit                          | MSB | 14   | 13         | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | LSB |
|                              | PAR | EF   | Data<13:0> |    |    |    |   |   |   |   |   |   |   |   |   |     |
| Bit Definition & Description |     |  |            |    |    |    |   |   |   |   |   |   |   |   |   |     |
| PAR                          |     | Parity bit (EVEN)  |            |    |    |    |   |   |   |   |   |   |   |   |   |     |
| EF                           |     | Error flag indicating a transmission error in a previous host transmission |            |    |    |    |   |   |   |   |   |   |   |   |   |     |
| Data                         |     | 14 bit addressed data  |            |    |    |    |   |   |   |   |   |   |   |   |   |     |

### Write Data Package (Value Written to AS5048A)

The write frame is compatible to the read frame and contains two additional bits, parity flag and R flag.

If the previous command was a write command a second package has to be transmitted.

**Figure 21:**  
SPI Write Data Package

| Data Package                 |     |   |             |    |    |    |   |   |   |   |   |   |   |   |   |     |
|------------------------------|-----|---|-------------|----|----|----|---|---|---|---|---|---|---|---|---|-----|
| Bit                          | MSB | 14  | 13          | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | LSB |
|                              | PAR | R   | Data <13:0> |    |    |    |   |   |   |   |   |   |   |   |   |     |
| Bit Definition & Description |     |   |             |    |    |    |   |   |   |   |   |   |   |   |   |     |
| PAR                          |     | Parity bit (EVEN)                               |             |    |    |    |   |   |   |   |   |   |   |   |   |     |
| R                            |     | Has to be 0                                     |             |    |    |    |   |   |   |   |   |   |   |   |   |     |
| Data                         |     | 14 bit data to write to former selected address |             |    |    |    |   |   |   |   |   |   |   |   |   |     |

## Register Description

**Figure 22:**  
SPI Register Map

| Address hex                 | Name                | Access Type | Bit | Symbol             | Default | Description   |
|-----------------------------|---------------------|-------------|-----|--------------------|---------|---|
| Control and Error Registers |                     |             |     |                    |         |   |
| x0000                       | NOP                 | R           | 13  | NOP                | 0       | No operation dummy information  |
|                             |                     |             | :   |                    |         |   |
|                             |                     |             | 0   |                    |         |   |
| x0001                       | Clear Error Flag    | R           | 13  | Not used           | n.a.    | Error register. All errors are cleared by access  |
|                             |                     |             | :   |                    |         |   |
|                             |                     |             | 3   |                    |         |   |
|                             |                     |             | 2   | Parity Error       | 0       |   |
|                             |                     |             | 1   | Command Invalid    |         |   |
|                             |                     |             | 0   | Framing Error      |         |   |
| x0003                       | Programming Control | R/W         | 13  | Not used           | 0       | Programming control register. Programming must be enabled before burning the fuse(s). After programming is a verification mandatory. See programming procedure. |
|                             |                     |             | :   |                    |         |   |
|                             |                     |             | 7   |                    |         |   |
|                             |                     |             | 6   | Verify             |         |   |
|                             |                     |             | 5   | Not used           |         |   |
|                             |                     |             | 4   |                    |         |   |
|                             |                     |             | 3   | Burn               |         |   |
|                             |                     |             | 2   | Reserved           |         |   |
|                             |                     |             | 1   |                    |         |   |
|                             |                     |             | 0   | Programming Enable |         |   |



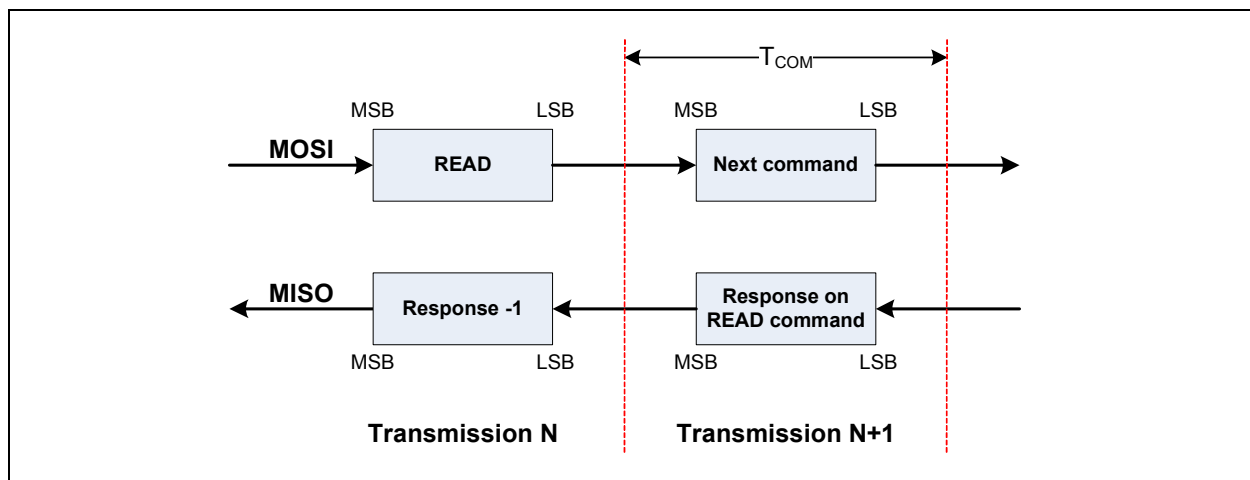
| Address hex                    | Name                                       | Access Type   | Bit | Symbol             | Default | Description  |
|--------------------------------|--|---------------|-----|--------------------|---------|--|
| Programmable Customer Settings |  |               |     |                    |         |  |
| x0016                          | OTP Register Zero Position Hi              | R/W + Program | 13  | Not used           | 0       | Zero Position value high byte  |
|                                |  |               | :   |                    |         |  |
|                                |  |               | 8   |                    |         |  |
|                                |  |               | 7   | Zero Position <13> | 0       |  |
|                                |  |               | :   | :                  | :       |  |
|                                |  |               | 0   | Zero Position <6>  | 0       |  |
| x0017                          | OTP Register Zero Position Low 6 LSBs      | R/W + Program | 13  | Not used           | 0       | Zero Position remaining 6 lower LSB's  |
|                                |  |               | :   |                    |         |  |
|                                |  |               | 6   |                    |         |  |
|                                |  |               | 5   | Zero Position <5>  | 0       |  |
|                                |  |               | :   | :                  | :       |  |
|                                |  |               | 0   | Zero Position <0>  | 0       |  |
| Readout Registers              |  |               |     |                    |         |  |
| x3FFD                          | Diagnostics + Automatic Gain Control (AGC) | R             | 13  | Not used           | n.a.    | Diagnostics flags  |
|                                |  |               | 12  |                    |         |  |
|                                |  |               | 11  | Comp High          | 0       |  |
|                                |  |               | 10  | Comp Low           | 0       |  |
|                                |  |               | 9   | COF                | 0       |  |
|                                |  |               | 8   | OCF                | 1       |  |
|                                |  |               | 7   | AGC value<7>       | 1       | Automatic Gain Control value.<br>0 decimal represents high magnetic field, 255 decimal represents low magnetic field |
|                                |  |               | :   | :                  | :       |  |
|                                |  |               | 0   | AGC value<0>       | 0       |  |
| x3FFE                          | Magnitude                                  | R             | 13  | Magnitude<13>      | 0       | Magnitude output value of the CORDIC   |
|                                |  |               | :   | :                  | :       |  |
|                                |  |               | 0   | Magnitude<0>       | 0       |  |
| x3FFF                          | Angle                                      | R             | 13  | Angle <13>         | 0       | Angle output value including zero position correction  |
|                                |  |               | :   | :                  | :       |  |
|                                |  |               | 0   | Angle<0>           | 0       |  |

## SPI Interface Commands

### READ Command

For a single *READ* command two transmission sequences are necessary. The first package written to the AS5048 contains the *READ* command (**MSB-1 high**) and the address the chip has to access, the second package transmitted to the AS5048 device can be *any command* the chip has to process next. The content of the desired register is available in the *MISO* register of the master device at the end of the second transmission cycle.

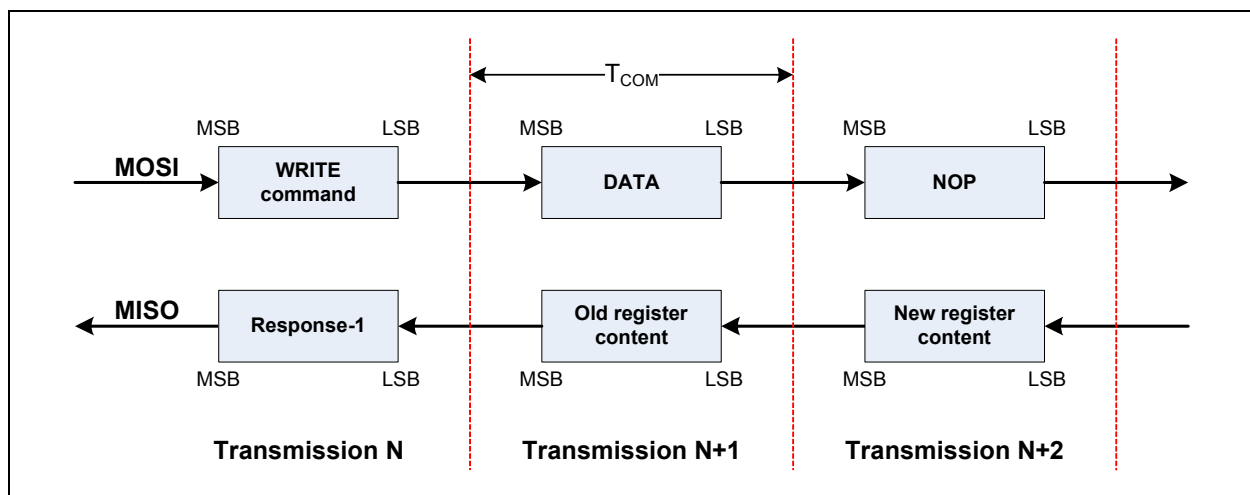
Figure 23:  
READ Command



### WRITE Command

A single *WRITE* command takes two transmission cycles. With a NOP command after the *WRITE* command you can verify the sent data with three transmission cycles because the data will be send back during the following command.

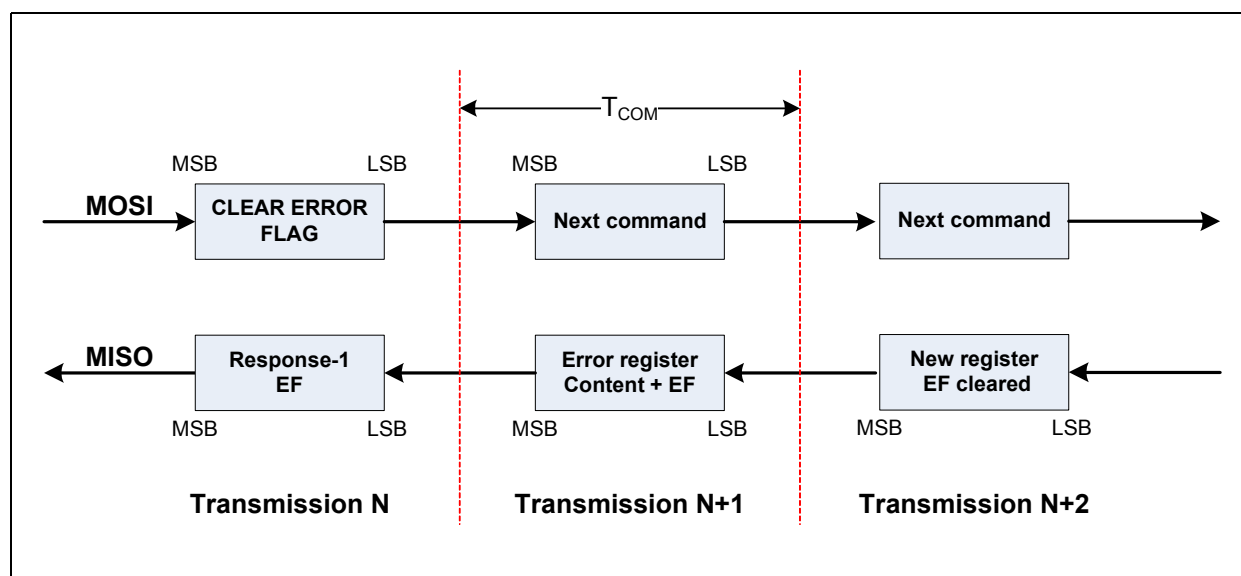
Figure 24:  
WRITE Command



## CLEAR ERROR FLAG Command

The *CLEAR ERROR FLAG* command is implemented as *READ* command. This command clears the *ERROR FLAG* which is contained in every *READ* frame. Before the *ERROR FLAG* is cleared the error register content comes back with the information which error type was occurred. On the next new *READ* register the *ERROR FLAG* is cleared.

**Figure 25:**  
**CLEAR ERROR FLAG Command**



The package necessary to perform a *CLEAR ERROR FLAG* is built up as follows.

**Figure 26:**  
**Clear Error Flag Command**

| CLEAR ERROR FLAG Command |     |    |    |    |    |    |   |   |   |   |   |   |   |   |   |     |
|--------------------------|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|-----|
| Bit                      | MSB | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | LSB |
|                          | PAR | 1  | 0  | 0  | 0  | 0  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1   |

Possible conditions which force the *ERROR FLAG* to be set:

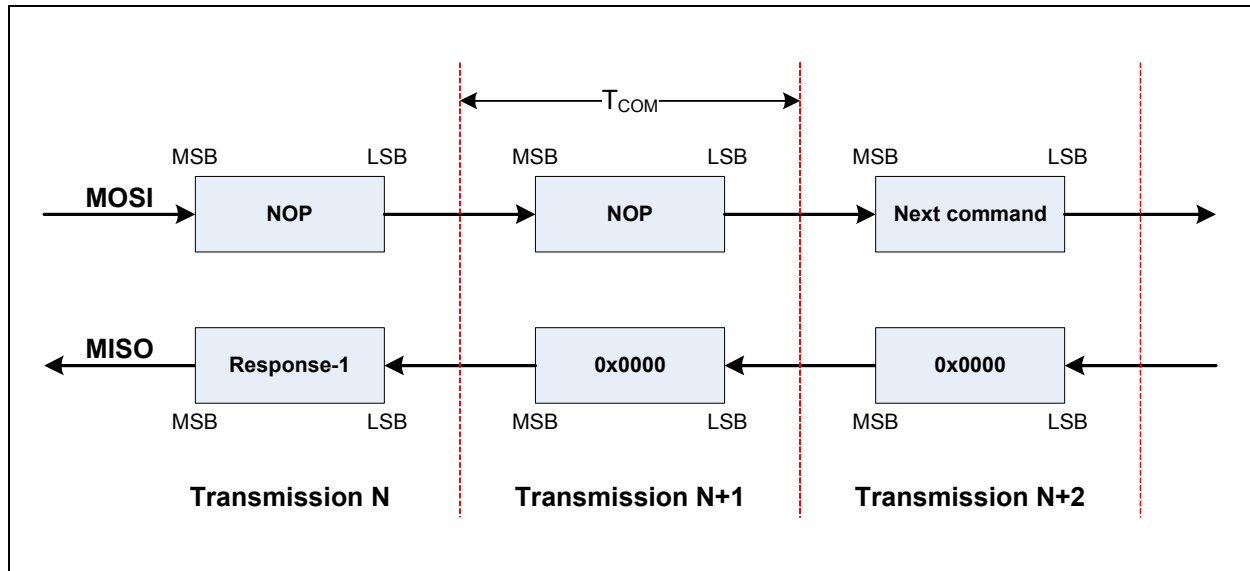
- Wrong parity
- Wrong number of clocks (no full transmission cycle or too many clocks)
- Invalid command
- Frame error

**Note(s):** If the error flag is set to high because of a communication problem the flag remains set until it will be cleared by the *CLEAR ERROR FLAG* command.

## NOP Command

The *NOP* command represents a dummy write to the AS5048.

**Figure 27:**  
NOP Command



The NOP command frame looks like follows.

**Figure 28:**  
NOP Command

| NOP Command |     |    |    |    |    |    |   |   |   |   |   |   |   |   |   |     |
|-------------|-----|----|----|----|----|----|---|---|---|---|---|---|---|---|---|-----|
| Bit         | MSB | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | LSB |
|             | 0   | 0  | 0  | 0  | 0  | 0  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0   |

The chip's response on this command is 0x0000

## I<sup>2</sup>C Interface

The AS5048B supports 2-wire high-speed I<sup>2</sup>C protocol in device mode. The host MCU (master) has to initiate the data transfers. The 7-bit device address of the slave depends on the state of the OTP I<sup>2</sup>C register 21 (0x15) bit 0... 4 + 2 I<sup>2</sup>C address selection pin 3 and 4.

Supported modes:

- Random/Sequential Read
- Byte/Page Write
- Standard : 0 to 100kHz clock frequency (slave mode)
- Fast Mode : 0 to 400kHz clock frequency (slave mode)
- High Speed: 0 to 3.4MHz clock frequency (slave mode)

The SDA signal is bidirectional and is used to read and write the serial data. The SCL signal is the clock generated by the host MCU, to synchronize the SDA data in read and write mode. The maximum I<sup>2</sup>C clock frequency is 3.4MHz, data are triggered on the rising edge of SCL.

### I<sup>2</sup>C Electrical Specification

**Figure 29:**  
I<sup>2</sup>C Electrical Specification

| Symbol           | Parameter   | Condition                | FS-mode+               |                           | HS-mode<br>C <sub>B</sub> =100pF |                           | HS-mode<br>C <sub>B</sub> =400pF |                           | Unit |
|------------------|---|--------------------------|------------------------|---------------------------|----------------------------------|---------------------------|----------------------------------|---------------------------|------|
|                  |   |                          | Min                    | Max                       | Min                              | Max                       | Min                              | Max                       |      |
| V <sub>IL</sub>  | LOW-Level Input Voltage   |                          | -0.5                   | 0.3V <sub>DDCORE</sub>    | -0.5                             | 0.3V <sub>DDCORE</sub>    | -0.5                             | 0.3V <sub>DDCORE</sub>    | V    |
| V <sub>IH</sub>  | HIGH-Level Input Voltage  |                          | 0.7V <sub>DDCORE</sub> | V <sub>DDCORE</sub> + 0.5 | 0.7V <sub>DDCORE</sub>           | V <sub>DDCORE</sub> + 0.5 | 0.7V <sub>DDCORE</sub>           | V <sub>DDCORE</sub> + 0.5 | V    |
| V <sub>hys</sub> | Hysteresis of Schmitt Trigger Inputs  | V <sub>DDCORE</sub> < 2V | 0.1V <sub>DDCORE</sub> | --                        | 0.1V <sub>DDCORE</sub>           | --                        | 0.1V <sub>DDCORE</sub>           | --                        | V    |
| V <sub>OL</sub>  | LOW-Level Output Voltage (open-drain or open-collector) at 3mA Sink Current | V <sub>DDCORE</sub> < 2V | --                     | 0.2V <sub>DDCORE</sub>    | --                               | 0.2V <sub>DDCORE</sub>    | --                               | 0.2V <sub>DDCORE</sub>    | V    |
| I <sub>OL</sub>  | LOW-Level Output Current  | V <sub>OL</sub> = 0.4V   | 20                     |                           | --                               | --                        | --                               | --                        | mA   |
| I <sub>CS</sub>  | Pull-up current of SCLH current source                                      |                          | --                     | --                        | 3                                | 12                        | 3                                | 12                        | mA   |
| t <sub>sp</sub>  | Pulse Width of Spikes that must be suppressed by the Input Filter           |                          | --                     | 50 <sup>(1)</sup>         | --                               | 10                        | --                               | 10                        | ns   |

| Symbol           | Parameter                               | Condition             | FS-mode+ |                    | HS-mode<br>C <sub>B</sub> =100pF |     | HS-mode<br>C <sub>B</sub> =400pF |     | Unit |
|------------------|---|-----------------------|----------|--------------------|----------------------------------|-----|----------------------------------|-----|------|
|                  |   |                       | Min      | Max                | Min                              | Max | Min                              | Max |      |
| I <sub>i</sub>   | Input Current at each I/O Pin           | Input Voltage between | -10      | +10 <sup>(2)</sup> | --                               | 10  | --                               | 10  | μA   |
| C <sub>B</sub>   | Total Capacitive Load for each Bus Line |                       | --       | 550                | --                               | 100 | --                               | 400 | pF   |
| C <sub>I/O</sub> | I/O Capacitance (SDA,SCL)               |                       | --       | 10                 | --                               | 10  | --                               | 10  | pF   |

**Note(s):**

1. Input filters on the SDA and SCL inputs suppress noise spikes of less than 50 ns.
2. I/O pins of Fast-mode and Fast-mode Plus devices must not obstruct the SDA and SCL lines if VDD is switched OFF.

### I<sup>2</sup>C Timing

**Figure 30:**  
I<sup>2</sup>C Timing

| Symbol              | Parameter  | Condition | FS-mode              |     | HS-mode<br>C <sub>B</sub> =100pF |      | HS-mode<br>C <sub>B</sub> =400pF (5) |      | Unit |
|---------------------|--|-----------|----------------------|-----|----------------------------------|------|--------------------------------------|------|------|
|                     |  |           | Min                  | Max | Min                              | Max  | Min                                  | Max  |      |
| f <sub>SCLK</sub>   | SCL clock Frequency                                  |           | --                   | 400 | --                               | 3400 | --                                   | 1700 | kHz  |
| t <sub>BUF</sub>    | Bus Free Time; time between STOP and START Condition |           | 500                  | --  | 500                              | --   | 500                                  | --   | ns   |
| t <sub>HD;STA</sub> | Hold Time; (Repeated) START Condition <sup>(1)</sup> |           | 260                  | --  | 160                              | --   | 160                                  | --   | ns   |
| t <sub>LOW</sub>    | LOW Period of SCL Clock                              |           | 500                  | --  | 160                              | --   | 320                                  | --   | ns   |
| t <sub>HIGH</sub>   | HIGH Period of SCL Clock                             |           | 260                  | --  | 60                               | --   | 120                                  | --   | ns   |
| t <sub>SU;STA</sub> | Setup Time for a Repeated START condition            |           | 260                  | --  | 160                              | --   | 160                                  | --   | ns   |
| t <sub>HD;DAT</sub> | Data Hold Time <sup>(2)</sup>                        |           | 0                    | 450 | 0                                | 70   | 0                                    | 150  | ns   |
| t <sub>SU;DAT</sub> | Data Setup Time <sup>(3)</sup>                       |           | 50                   | --  | 10                               | --   | 10                                   | --   | ns   |
| t <sub>R</sub>      | Rise Time of SDA and SCL Signals                     |           | 20+0.1C <sub>b</sub> | 120 | --                               | --   | --                                   | --   | ns   |

| Symbol       | Parameter  | Condition                  | FS-mode      |                    | HS-mode<br>$C_B=100\text{pF}$ |     | HS-mode<br>$C_B=400\text{pF}$ (5) |     | Unit |
|--------------|--|----------------------------|--------------|--------------------|-------------------------------|-----|-----------------------------------|-----|------|
|              |  |                            | Min          | Max                | Min                           | Max | Min                               | Max |      |
| $t_F$        | Fall time of SDA and SCL signals   |                            | $20+0.1C_b$  | 120 <sup>(4)</sup> | --                            | --  | --                                | --  | ns   |
| $t_{rCL}$    | Rise time of SCLH signal   | Ext. pull-up source of 3mA | --           | --                 | 10                            | 40  | 20                                | 80  | ns   |
| $t_{rCL1}$   | Rise time of SCLH signal after repeated START condition and after an acknowledge bit | Ext. pull-up source of 3mA | --           | --                 | 10                            | 80  | 20                                | 160 | ns   |
| $t_{fCL}$    | Output rise time of SCLH signal  | Ext. pull-up source of 3mA | --           | --                 | 10                            | 40  | 20                                | 80  | ns   |
| $t_{rDA}$    | Output rise time of SDAH signal  |                            | --           | --                 | 10                            | 80  | 20                                | 160 | ns   |
| $t_{fDA}$    | Output rise time of SDAH signal  |                            | --           | --                 | 10                            | 80  | 20                                | 160 | ns   |
| $t_{SU;STO}$ | Setup Time for STOP Condition  |                            | 260          | --                 | 160                           | --  | 160                               | --  | ns   |
| $V_{nL}$     | Noise margin at LOW level  |                            | $0.1V_{DDp}$ | --                 | $0.1V_{DDp}$                  | --  | $0.1V_{DDp}$                      | --  | V    |
| $V_{nH}$     | Noise margin at HIGH level   |                            | $0.2V_{DDp}$ | --                 | $0.2V_{DDp}$                  | --  | $0.2V_{DDp}$                      | --  | V    |

**Note(s):**

1. After this time the first clock is generated.
2. A device must internally provide a minimum hold time (120ns / max 250ns for Fast-mode Plus, 80ns / max 150ns for High-speed mode) for the SDA signal (referred to the  $V_{IHmin}$  of the SCL) to bridge the undefined region of the falling edge of SCL.
3. A fast-mode device can be used in standard-mode system, but the requirement  $t_{SU;DAT} = 250\text{ns}$  must then be met. This is automatically the case if the device does not stretch the LOW period of the SCL signal. If such a device does stretch the LOW period of the SCL signal, it must output the next data bit to the SDA line  $t_{Rmax} + t_{SU;DAT} = 1000 + 250 = 1250\text{ns}$  before the SCL line is released.
4. In Fast-mode Plus, fall time is specified the same for both output stage and bus timing. If series resistors are used this has to be considered for bus timing.
5. For capacitive bus loads between 100pF and 400pF, the timing parameters must be linearly interpolated

### Register Table

The following registers / functions are accessible over the serial I<sup>2</sup>C interface.

**Figure 31:**  
**Register Map I<sup>2</sup>C**

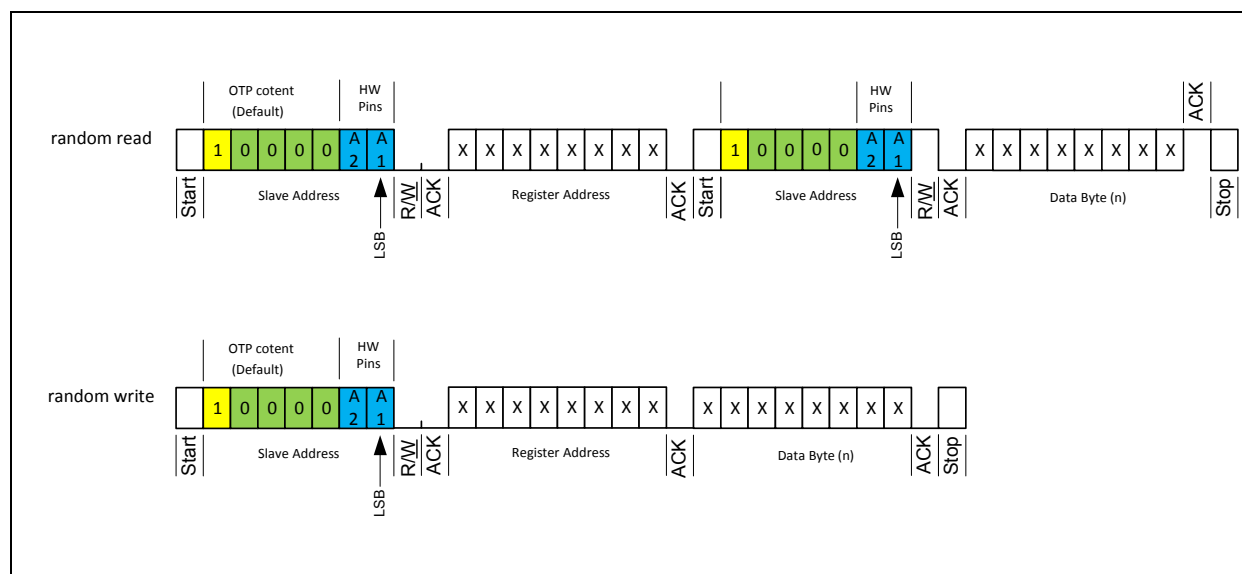
| Address hex                    | Name                                  | Access Type   | Bit | Symbol                      | Default             | Description   |
|--------------------------------|---------------------------------------|---------------|-----|-----------------------------|---------------------|---|
| Control OTP                    |                                       |               |     |                             |                     |   |
| x03                            | Programming Control                   | R/W           | 7   | Not used                    | 0                   | Programming control register. Programming must be enabled before burning the fuse(s). After programming is an verification mandatory. See programming procedure.              |
|                                |                                       |               | 6   | Verify                      |                     |   |
|                                |                                       |               | 5   | Not used                    |                     |   |
|                                |                                       |               | 4   |                             |                     |   |
|                                |                                       |               | 3   | Burn                        |                     |   |
|                                |                                       |               | 2   | Reserved                    |                     |   |
|                                |                                       |               | 1   |                             |                     |   |
|                                |                                       |               | 0   | Programming Enable          |                     |   |
| Programmable Customer Settings |                                       |               |     |                             |                     |   |
| x15                            | I <sup>2</sup> C slave address        | R/W           | 7   | Not used                    | n.a.                | I <sup>2</sup> C slave address slave address consist of 5 bits (MSBs) and the hardware setting of Pins A1 and A2 I <sup>2</sup> C address <4> is the inversion defined as '1' |
|                                |                                       |               | :   |                             |                     |   |
|                                |                                       |               | 5   |                             |                     |   |
|                                |                                       |               | 4   | I <sup>2</sup> C address<4> | internally inverted |   |
|                                |                                       |               | :   | :                           | :                   |   |
|                                |                                       |               | 0   | I <sup>2</sup> C address<0> | 0                   |   |
| x16                            | OTP Register Zero Position Hi         | R/W + Program | 7   | Zero Position <13>          | 0                   | Zero Position value high byte   |
|                                |                                       |               | :   | :                           | :                   |   |
|                                |                                       |               | 0   | Zero Position <6>           | 0                   |   |
| x17                            | OTP Register Zero Position Low 6 LSBs | R/W + Program | 7   | Not used                    | n.a.                | Zero Position remaining 6 lower LSB's   |
|                                |                                       |               | 6   |                             |                     |   |
|                                |                                       |               | 5   | Zero Position <5>           | 0                   |   |
|                                |                                       |               | :   | :                           | :                   |   |
|                                |                                       |               | 0   | Zero Position <0>           | 0                   |   |



| Address hex       | Name                   | Access Type | Bit | Symbol        | Default   | Description   |   |
|-------------------|------------------------|-------------|-----|---------------|-----------|---|---|
| Readout Registers |                        |             |     |               |           |   |   |
| xFA               | Automatic Gain Control | R           | 7   | AGC value<7>  | 1         | Automatic Gain Control value.<br>0 decimal represents high magnetic field 255 decimal represents low magnetic field |   |
|                   |                        |             | :   | :             | :         |   |   |
|                   |                        |             | 0   | AGC value<0>  | 0         |   |   |
| xFB               | Diagnostics            | R           | 7   | Not used      | n.a.      | Diagnostic flags  |   |
|                   |                        |             | :   |               |           |   |   |
|                   |                        |             | 4   |               |           |   |   |
|                   |                        |             | 3   | Comp High     | 0         |   |   |
|                   |                        |             | 2   | Comp Low      | 0         |   |   |
|                   |                        |             | 1   | COF           | 0         |   |   |
|                   |                        |             | 0   | OCF           | 1         |   |   |
| xFC               | Magnitude              | R           | 7   | Magnitude<13> | 0         | Magnitude output value of the CORDIC  |   |
|                   |                        |             | :   | :             | :         |   |   |
|                   |                        |             | 0   | Magnitude<6>  | 0         |   |   |
| xFD               |                        | R           | 7   | Not used      | n.a.      |   |   |
|                   |                        |             | 6   |               |           |   |   |
|                   |                        |             | 5   | Magnitude<5>  | 0         |   |   |
|                   |                        |             | :   | :             | :         |   |   |
|                   |                        |             | 0   | Magnitude<0>  | 0         |   |   |
| xFE               |                        | Angle       | R   | 7             | Angle<13> | 0   | Angle output value including zero position correction |
|                   |                        |             |     | :             | :         | :   |   |
|                   |                        |             |     | 0             | Angle<6>  | 0   |   |
| xFF               | R                      |             | 7   | Not used      | n.a.      |   |   |
|                   |                        |             | 6   |               |           |   |   |
|                   |                        |             | 5   | Angle<5>      | 0         |   |   |
|                   |                        |             | :   | :             | :         |   |   |
|                   |                        |             | 0   | Angle<0>      | 0         |   |   |

## I<sup>2</sup>C Slave address

**Figure 32:**  
Slave Address Construction



**Note(s):**

1. It's important to use a STOP condition only after a complete read or write sequence.

The slave address consists of the hardware setting on pins A1, A2. The MSB of the slave address (yellow) is internally inverted. This means that by default the resulting data is '1'. A read of the I<sup>2</sup>C slave address register 21 will return a '0' at the MSB.

## PWM Interface

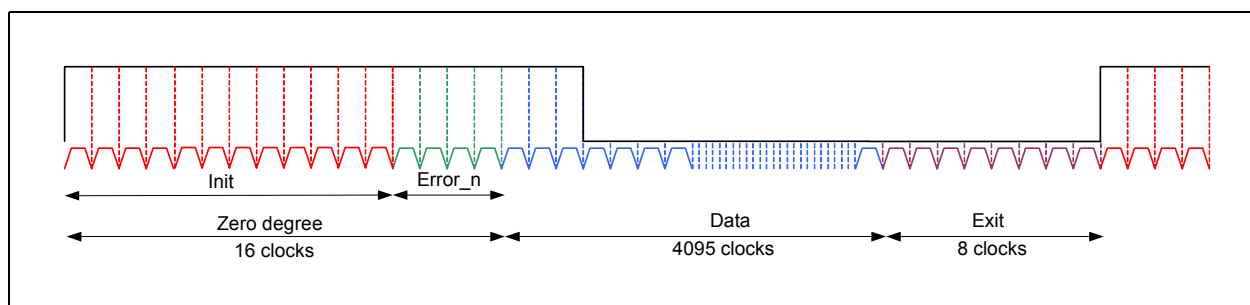
The AS5048 provides a pulse width modulated output (PWM), whose duty cycle is proportional to the measured angle. The PWM frequency is internally trimmed to an accuracy of  $\pm 10\%$  over full temperature range. This tolerance can be cancelled by measuring the complete duty cycle.

The PWM signal consists of different sections:

- Init:  
12 clocks → PWM = 'high'
- Error\_n:  
4 clocks → PWM = 'not(system\_error)'
- Data:  
4095 clocks → PWM = 'angle\_zero' / 'low' (in case of error)
- Exit:  
8 clocks → PWM = 'low'

In case of an error the data section is set to zero.

**Figure 33:**  
PWM Format



**Figure 34:**  
PWM Period and Resolution

| Parameter        | Symbol | Value | Unit |
|------------------|--------|-------|------|
| PWM Frequency    | F_PWM  | 1     | KHz  |
| PWM Pulse period | T_PWM  | 4119  | bit  |

## Application Information

### Programming of the AS5048

**Programming of the Zero Position:** The absolute angle position can be permanent programmed over the interface. This could be useful for random placement of the magnet on the rotation axis. A readout at the mechanical zero position can be performed and written back into the IC. With permanent programming the position is non-reversible stored in the IC. This programming can be performed only once.

To simplify the calculation of the zero position it is only needed to write the value in the IC which was read out before from the angle register.

**Programming Sequence with Verification:** To program the zero position is needed to perform following sequence:

1. Write 0 into OTP zero position register to clear
2. Read angle information
3. Write previous read angle position into OTP zero position register

*Now the zero position is set.*

*If you want to burn it to the OTP register send:*

4. Set the Programming Enable bit in the OTP control register
5. Set the Burn bit to start the automatic programming procedure
6. Read angle information (equals to 0)
7. Set the Verify bit to load the OTP data again into the internal registers
8. Read angle information (equals to 0)

The programming can either be performed in 5V operation using the internal LDO, or in 3V operation but using a minimum supply voltage of 3.3V. In case of 3V operation, also a 10µF capacitor is required on the VDD3 pin.

**Programming the I<sup>2</sup>C Slave address:** For informations of programming the I<sup>2</sup>C Slave address please refer to our application note covering this topic.

## Diagnostic Functions of the AS5048

The AS5048 provides diagnostics functions of the IC and also diagnostic functions of the magnetic input field

Following diagnostic flags are available:

See [Figure 22](#) register address x3FFD (AS5048A) or [Figure 31](#) register address 251 dec (AS5048B)

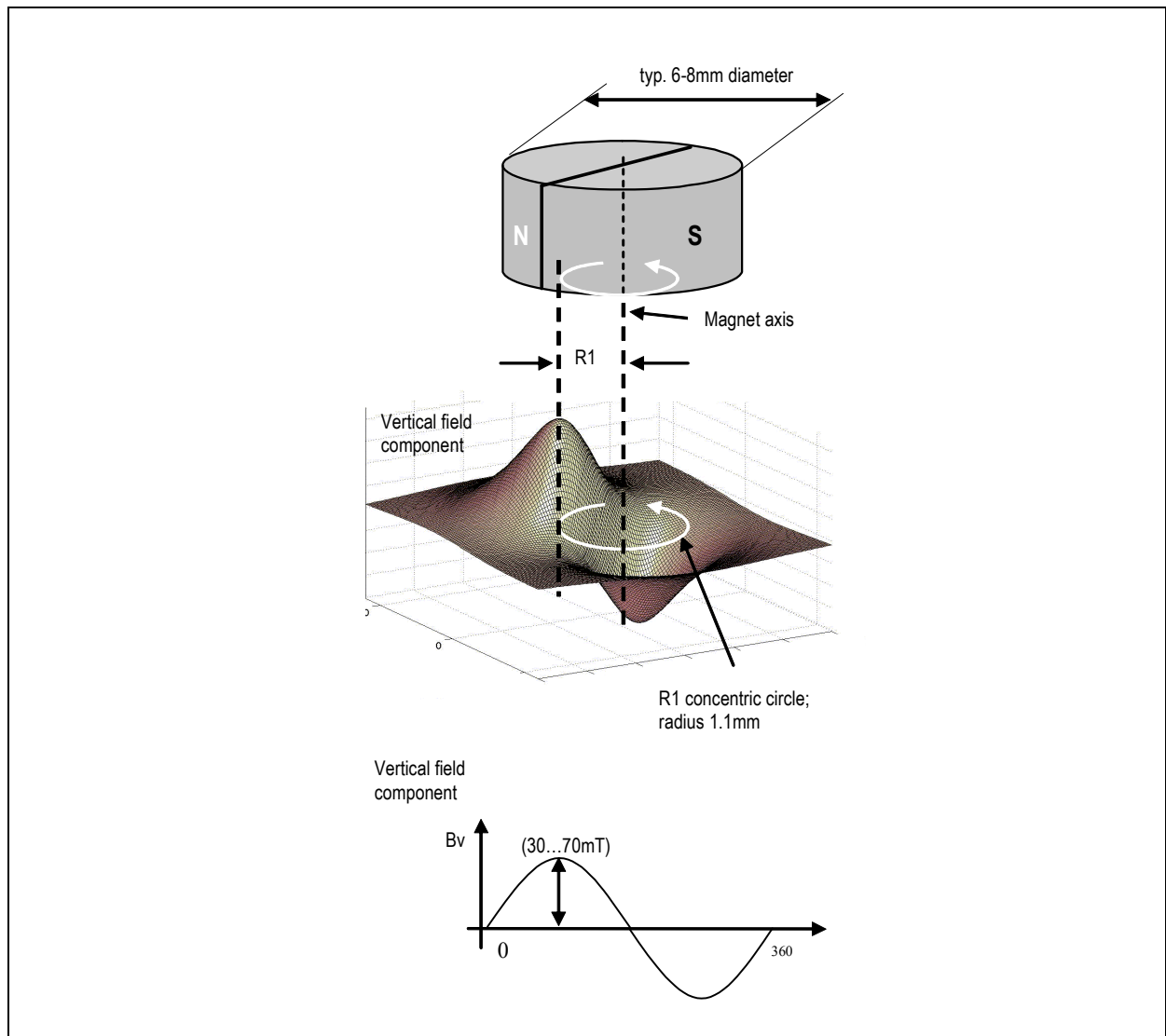
- **OCF (Offset Compensation Finished)**, logic high indicates the finished Offset Compensation Algorithm. After power up the flag remains always to logic high.
- **COF (CORDIC Overflow)**, logic high indicates an out of range error in the CORDIC part. When this bit is set, the angle and magnitude data is invalid. The absolute output maintains the last valid angular value.
- **COMP low**, indicates a high magnetic field. It is recommended to monitor in addition the magnitude value.
- **COMP high**, indicated a weak magnetic field. It is recommended to monitor the magnitude value.

## Choosing the Proper Magnet

The AS5048 works with a variety of different magnets in size and shape. A typical magnet could be 6-8 mm in diameter and  $\geq 2.5\text{mm}$  in height. The magnetic field strength perpendicular to the die surface has to be in the range of  $\pm 30\text{mT}$  ...  $\pm 70\text{mT}$  (peak).

The magnet's field strength should be verified using a gauss-meter. The magnetic flux  $B_z$  at a given distance, along a concentric circle with a radius of 1.1mm (R1), should be in the range of  $\pm 30\text{mT}$ ...  $\pm 70\text{mT}$ .

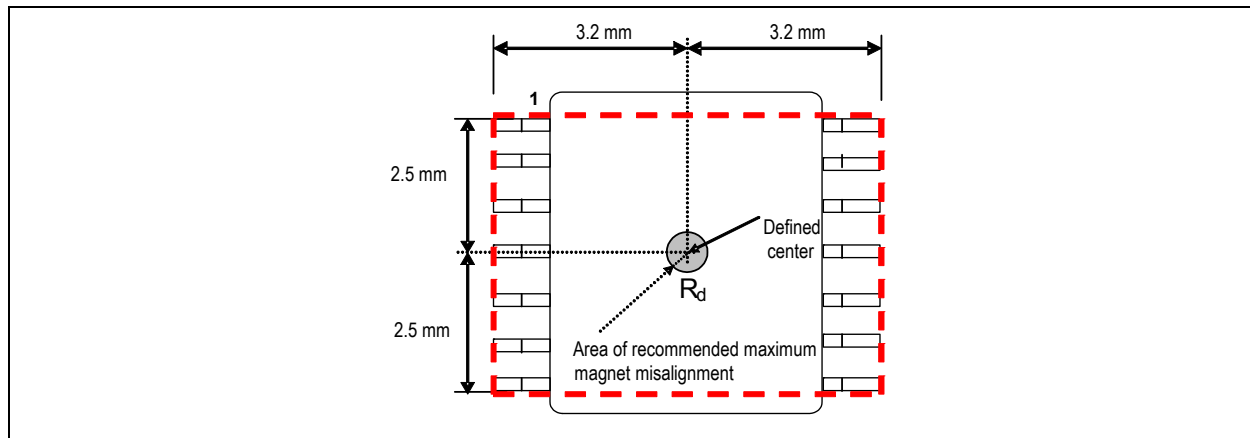
**Figure 35:**  
Typical Magnet and Magnetic Flux Distribution



## Physical Placement of the Magnet

The best linearity can be achieved by placing the center of the magnet exactly over the defined center of the chip as shown in the drawing below:

**Figure 36:**  
Defined Chip Center and Magnet Displacement Radius



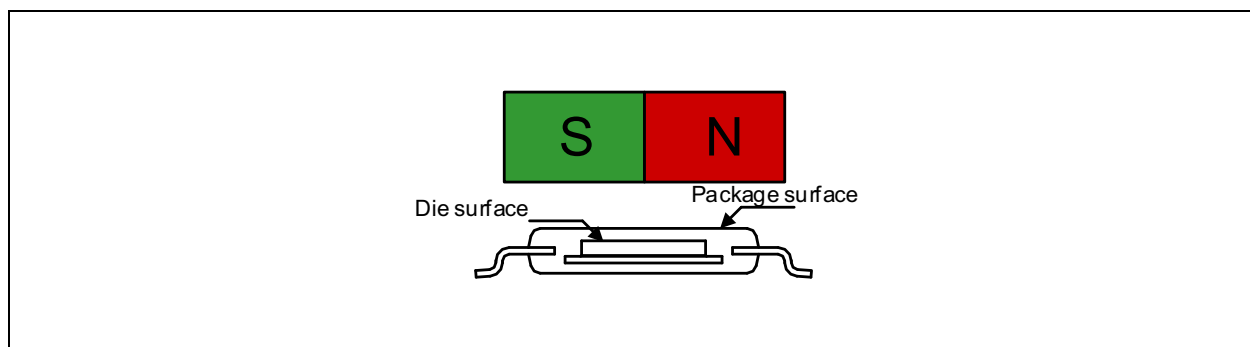
## Magnet Placement

The magnet's center axis should be aligned within a displacement radius  $R_d$  of 0.25 mm (larger magnets allow more displacement e.g. 0.5 mm) from the defined center of the IC.

The magnet may be placed below or above the device. The distance should be chosen such that the magnetic field on the die surface is within the specified limits. The typical distance "z" between the magnet and the package surface is 0.5mm to 2.5mm, provided the use of the recommended magnet material and dimensions (6mm x 3mm). Larger distances are possible, as long as the required magnetic field strength stays within the defined limits.

However, a magnetic field outside the specified range may still produce usable results, but the out-of-range condition will be indicated by indication flags.

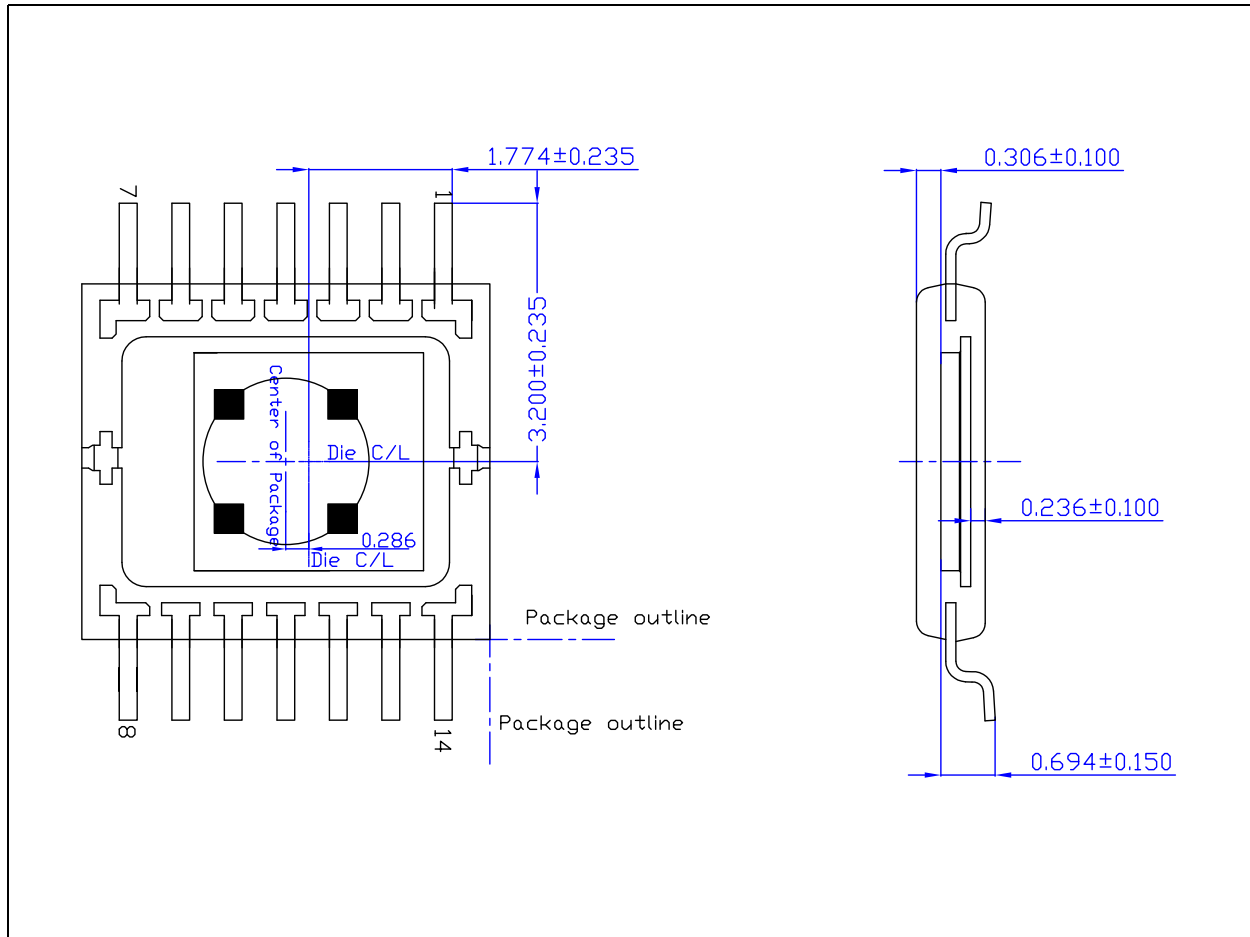
**Figure 37:**  
Vertical Placement of the Magnet



## Mechanical Data

The internal Hall elements are placed in the center of the package on a circle with a radius of 1.1 mm.

**Figure 38:**  
Hall Element Positions



**Note(s):**

1. All dimensions in mm.
2. Die thickness 203µm nom.
3. Adhesive thickness 30 ± 15µm.
4. Leadframe downset 152 ± 25 µm.
5. Leadframe thickness 125 ± 8 µm.



Package Drawings & Markings

Package type: TSSOP14

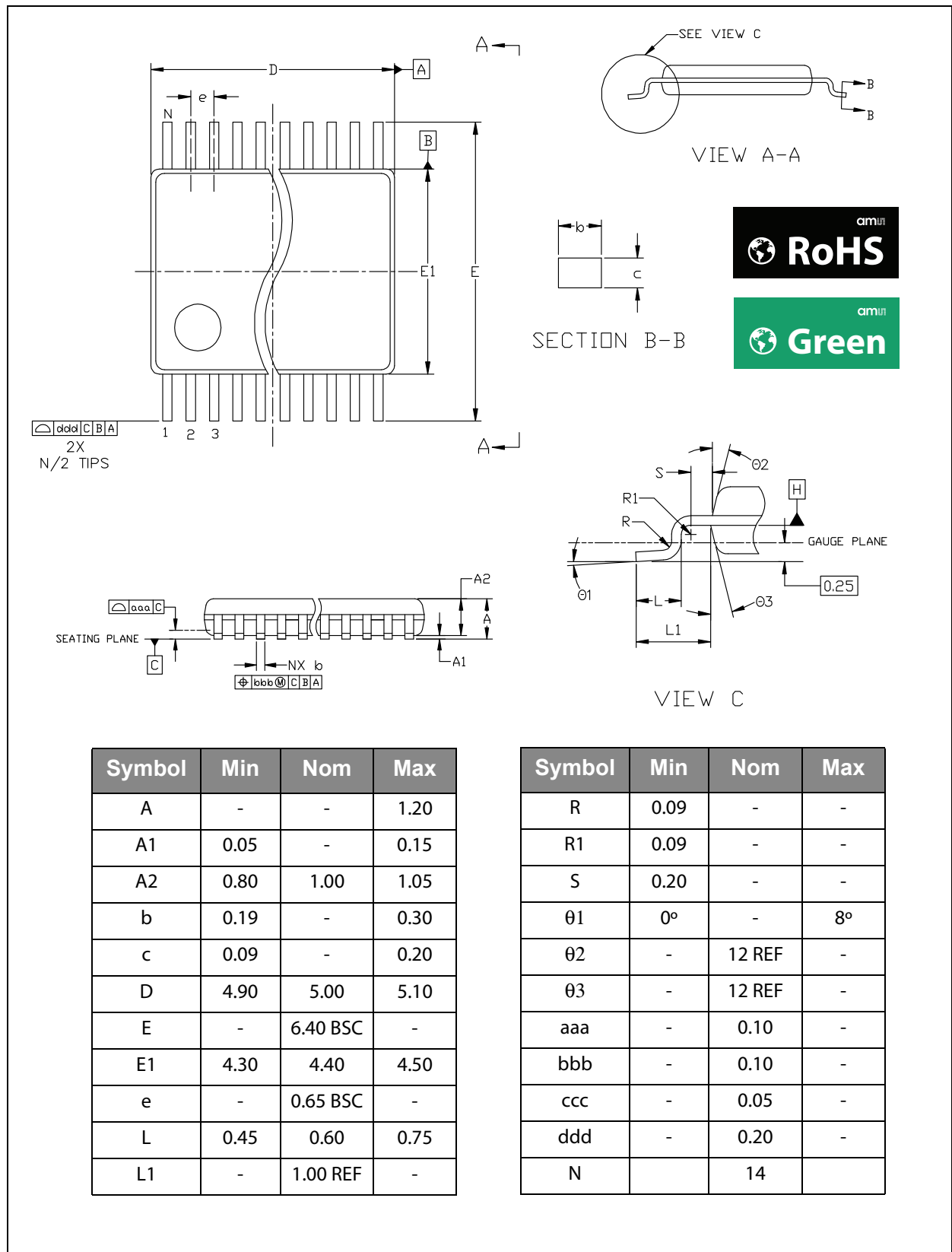
Figure 39:  
Package Markings for AS5048A & AS5048B



Figure 40:  
Package Code YYWWMZZ

| YY  | WW                 | M                | ZZ                            |
|---|--------------------|------------------|-------------------------------|
| Last two digits of the manufacturing year | Manufacturing week | Plant identifier | Letters for free traceability |

**Figure 41:**  
**14-Lead Thin Shrink Small Outline Package TSSOP-14**



**Note(s):**

1. Dimensioning & tolerancing confirm to ASME Y14.5M-1994.
2. All dimensions are in millimeters. Angles are in degrees.

## Ordering & Contact Information

The devices are available as standard products.

**Figure 42:**  
**Ordering Information**

| Ordering Code | Package  | Description  | Delivery Form |
|---------------|----------|--|---------------|
| AS5048A-HTSP  | TSSOP 14 | 14 –Bit Programmable Magnetic Rotary Encoder with SPI-Interface              | Tape & Reel   |
| AS5048B-HTSP  | TSSOP 14 | 14 –Bit Programmable Magnetic Rotary Encoder with I <sup>2</sup> C-Interface | Tape & Reel   |

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### Headquarters

ams AG  
Tobelbader Strasse 30  
8141 Premstaetten  
Austria, Europe

Tel: +43 (0) 3136 500 0

Website: [www.ams.com](http://www.ams.com)

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|--------------------------|-----------------|--|
| Product Preview          | Pre-Development | Information in this datasheet is based on product ideas in the planning phase of development. All specifications are design goals without any warranty and are subject to change without notice  |
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**Note(s):**

1. Page and figure numbers for the previous version may differ from page and figure numbers in the current revision.
2. Correction of typographical errors is not explicitly mentioned.

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