

## Key Features

- Contact-less high resolution encoding over a full turn of 360 degrees
- Flexible system due to user programmable incremental output modes:
  - 10, 9, 8 or 7 bit user programmable resolution
  - Quadrature A/B and index output signal
  - Single channel output and direction indication
  - U-V-W commutation signals for brush-less DC motors
- Absolute angular position mode:
  - 10-bit resolution providing 1024 absolute positions per 360 degrees (step size ~ 0.35 deg)
- Synchronous serial interface (SSI) output for absolute position data
- Pulse width modulated (PWM) output, duty cycle proportional to angle
- User programmable zero / index position
- Failure detection mode for magnet placement monitoring
- Rotational speeds up to 10,000 rpm (incremental output)
- Push button functionality detects movement of magnet in Z-axis
- Two supply voltages: 3.3 V or 5 V
- Wide temperature range: - 40°C to + 125°C
- Small package: SSOP 16 (5.3mm x 6.2mm)

## Benefits

- World's smallest multiple output magnetic rotary encoder
- Tolerant to magnetic source misalignment
- Failure detection feature
- Complete system-on-chip:
  - Flexible system solution provides absolute, incremental and PWM digital outputs simultaneously
  - minimum number of external components needed
- Serial read-out of multiple AS5040 devices using daisy chain mode
- Ideal for applications in harsh environments due to contact-less position sensing

## General Description

The AS5040 is a system-on-chip, combining integrated Hall elements, analog front end and digital signal processing in a single device. It provides incremental output signals and the absolute angular position of a magnet that is placed either above or below the device.

The AS5040 can be configured to specific customer requirements by programming the integrated OTP (one time programmable) register. An internal voltage regulator allows the AS5040 to operate at either 3.3 V or 5 V supplies.

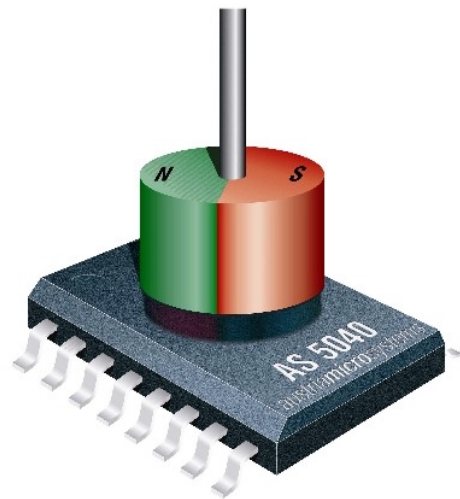


Figure 1: Typical arrangement AS5040 and magnet

## Applications

- Industrial applications such as:
  - Motion control
  - Robotics
  - Brush-less DC motor commutation
  - Power tools
- Automotive applications:
  - Steering wheel position sensing
  - Gas pedal position sensing
  - Transmission gearbox encoder
  - Headlight position control
  - Power seat position indicator
- Office equipment: printers, scanners, copiers
- Replacement of optical encoders
- Front panel rotary switches and potentiometers

## Pin Configuration

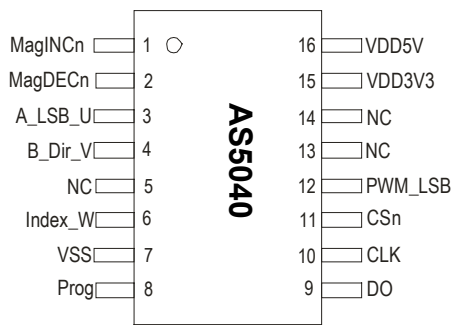


Figure 2: Pin configuration SSOP16

## Pin Description

Table 2 shows the description of each pin of the standard SSOP16 package (Shrink Small Outline Package, 16 leads, body size: 5.3mm x 6.2mm; see Figure 2).

Pins 7, 15 and 16 are supply pins, Pins 5, 13 and 14 are for internal use and must not be connected.

Pins 1 and 2 are the magnetic field change indicators, MagINCn and MagDECn (magnetic field strength increase or decrease through variation of the distance between the magnet and the device). These outputs can be used to detect the valid magnetic field range. Furthermore those indicators can also be used for contact-less push-button functionality.

Pins 3, 4 and 6 are the incremental pulse output pins. The functionality of these pins can be configured through programming the one-time programmable (OTP) register:

Output mode	Pin3	Pin4	Pin6	Pin12
01 quadrature	A	B	Index	PWM
02 single channel	LSB	direction	Index	PWM
03 commutation	U	V	W	LSB

Table 1: pin assignment for the different incremental output modes

### Mode1 - Quadrature A/B output:

Represents the default quadrature A/B signal mode.

### Mode2 – Single channel output:

Configures Pin 3 to deliver up to 512 pulses (up to 1024 state changes) per revolution. It is equivalent to the state-change of the LSB (least significant bit) of the absolute position value. Pin 4 provides the information of the rotational direction.

Both modes (mode 1 and mode 2) provide an index signal (1 pulse/revolution) with an adjustable width of one LSB or three LSBs.

Pin	Symbol	Type	Description
1	MagINCn	DO_OD	Magnet Field <b>M</b> agnitude <b>I</b> ncrease; active low, indicates a distance reduction between the magnet and the device surface.
2	MagDECn	DO_OD	Magnet Field <b>M</b> agnitude <b>D</b> ecrease; active low, indicates a distance increase between the device and the magnet.
3	A_LSB_U	DO	<i>Mode1</i> : Quadrature <b>A</b> channel <i>Mode2</i> : Least <b>S</b> ignificant Bit <i>Mode3</i> : <b>U</b> signal (phase1)
4	B_Dir_V	DO	<i>Mode1</i> : Quadrature <b>B</b> channel quarter period shift to channel A. <i>Mode2</i> : <b>D</b> irection of Rotation <i>Mode3</i> : <b>V</b> signal (phase2)
5	NC	-	must be left unconnected
6	Index_W	DO	<i>Mode1 and Mode2</i> : <b>I</b> ndex signal indicates the absolute zero position <i>Mode3</i> : <b>W</b> signal (phase3)
7	VSS	S	Negative Supply Voltage (GND)
8	Prog	DI_PD	<b>P</b> rogramming and <b>D</b> ata <b>I</b> nput for Mode configuration, incremental resolution setting, Zero-Position Programming and Daisy Chain mode configuration. Internal pull-down resistor (~74kΩ)
9	DO	DO_T	<b>D</b> ata <b>O</b> utput of Synchronous Serial Interface
10	CLK	DI, ST	<b>C</b> lock <b>I</b> nput of Synchronous Serial Interface; Schmitt-Trigger input
11	CSn	DI_PU, ST	<b>C</b> hip <b>S</b> elect, active low; Schmitt-Trigger input, internal pull-up resistor (~50kΩ)
12	PWM_LSB	DO	<b>P</b> ulse <b>W</b> idth <b>M</b> odulation of approx. 1kHz; <b>L</b> SB in <i>Mode3</i>
13	NC	-	must be left unconnected
14	NC	-	must be left unconnected
15	VDD3V3	S	3V-Regulator Output
16	VDD5V	S	Positive Supply Voltage 5 V

Table 2: Pin description SSOP16

DO_OD	digital output open drain	S	supply pin
DO	digital output	DI	digital input
DI_PD	digital input pull-down	DO_T	digital output /tri-state
DI_PU	digital input pull-up	ST	schmitt-trigger input

### Mode3 – Brush-less DC motor commutation mode:

The alternative third mode provides commutation signals for electrical motors with either one pole pair or two pole pairs. In this mode Pin 12 provides the LSB output instead of the PWM (Pulse-Width-Modulation) signal.

Pin 8 (Prog) can be used as digital input to shift serial data through the device (Daisy Chain Configuration). This pin is also necessary to program the different interface modes, the incremental resolution and the zero-position into the O(SSI) to readout the absolute position data of the magnet.

Pin 11 Chip Select (CSn; active low) selects a device within a network of AS5040 encoders. A "logic high" at CSn forces the digital tri-state output into the high ohmic state. A "high" pulse with a minimum duration of  $t_{CSn}$  also initiates a subsequent readout of the current angular value.

Pin 12 allows a single wire output of the 10bit absolute position value. The value is encoded into a pulse width modulated signal ((absolute position code + 1)  $\mu$ s). By using an external low pass filter, the PWM angular position output can be converted to an analog voltage, making a direct replacement of potentiometers possible.

## Functional Description

The AS5040 is manufactured in a CMOS standard process and uses a spinning current Hall technology for sensing the magnetic field distribution across the surface of the chip.

The integrated Hall elements are placed around the center of the device and deliver a voltage representation of the magnetic field at the surface of the IC.

Through Sigma-Delta Analog / Digital Conversion and Digital Signal-Processing (DSP) algorithms, the AS5040 provides accurate high-resolution absolute angular position information. For this purpose a Coordinate Rotation Digital Computer (CORDIC) calculates the angle and the magnitude of the Hall array signals.

The DSP is also used to provide digital information at the outputs MagINCn and MagDECn that indicate movements of the used magnet towards or away from the device's surface.

A small low cost diametrically magnetized (two-pole) standard magnet provides the angular position information (see Figure 15).

The AS5040 senses the orientation of the magnetic field and calculates a 10-bit binary code. This code can be accessed via a Synchronous Serial Interface (SSI). In addition, an absolute angular representation is given by a Pulse Width Modulated signal at pin 12 (PWM). This PWM signal output also allows the generation of a direct proportional analogue voltage, by using an external Low-Pass-Filter.

Besides the absolute angular position information the device simultaneously provides incremental output signals. The various incremental output modes can be selected by programming the OTP mode register bits according to Table 7. As long as no programming voltage is applied at pin PROG, the new setting can be overwritten at any time and will be reset to default when power is turned off. To make the setting permanent, the OTP register must be zapped (see Figure 12). The default setting represents the quadrature A/B mode including the Index signal with a pulse width of 1 LSB. The Index signal is logic high at the user's programmed position.

The AS5040 is tolerant to magnet misalignment and magnetic stray fields due to differential measurement technique and Hall sensor conditioning circuitry.

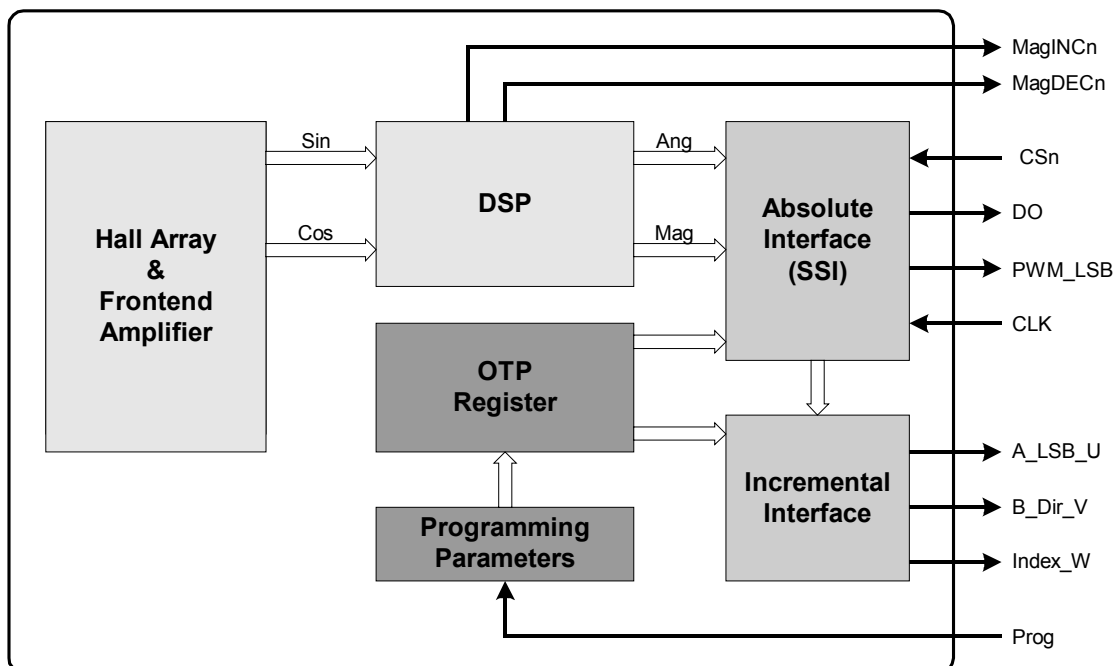


Figure 3 AS5040 Block Diagram  
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## 10 bit Absolute Angular Position Output

### Synchronous Serial Interface SSI

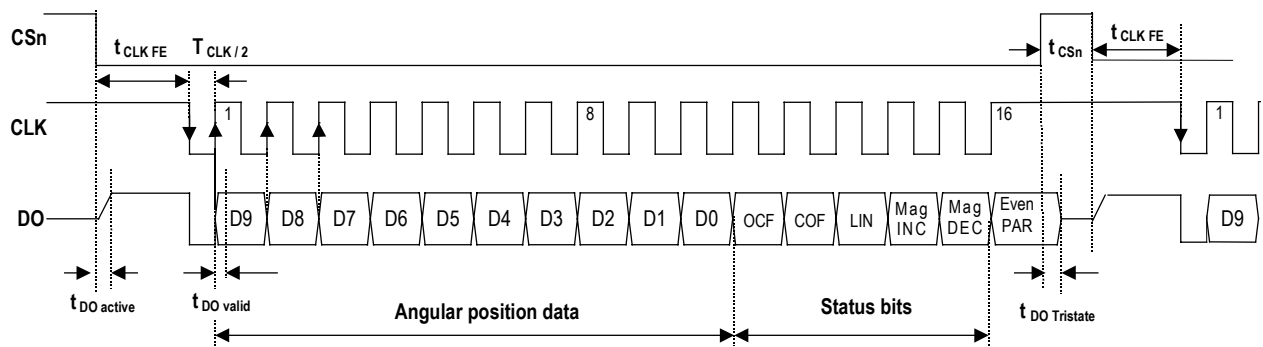


Figure 4: ynchronous serial interface with absolute angular position data

If CSn changes to logic low, Data Out (DO) will change from high impedance (tri-state) to logic high and the read-out will be initiated.

1. After a minimum time  $t_{CLK FE}$ , data is latched into the output shift register with the first falling edge of CLK.
2. Each subsequent rising CLK edge shifts out one bit of data.
3. The serial word contains 16 bits, the first 10 bits are the angular information D[9:0], the subsequent 6 bits contain system information, about the validity of data such as OCF, COF, LIN, Parity and Magnetic Field status (increase/decrease) .
4. A subsequent measurement is initiated by a "high" pulse at CSn with a minimum duration of  $t_{CSn}$ .

#### Data Content:

**D9:D0** absolute angular position data (MSB is clocked out first)

**OCF (Offset Compensation Finished)**, logic high indicates the finished Offset Compensation Algorithm

**COF (Cordic Overflow)**, logic high indicates an out of range error in the CORDIC part. When this bit is set, the data at D9:D0 is invalid. The absolute output maintains the last valid angular value. This Alarm may be resolved by bringing the magnet within the X-Y-Z tolerance limits.

**LIN (Linearity Alarm)**, logic high indicates that the input field generates a critical output linearity. When his bit is set, the data at D9:D0 may still be used, but can contain invalid data. This Warning may be resolved by bringing the magnet within the X-Y-Z tolerance limits.

**MagINC, (Magnitude Increase)** becomes HIGH, when the magnet is pushed towards the IC, thus the magnetic field strength is increasing.

**MagDEC, (Magnitude Decrease)** becomes HIGH, when the magnet is pulled away from the IC, thus the magnetic field strength is decreasing.

Both signals HIGH indicate a magnetic field that is out of the allowed range (see Table 3).

**PAR** Even Parity bit for transmission error detection of bits 1...13 (D9...D0,OCF,COF,LIN)

MagINC	MagDEC	Description
0	0	No distance change Magnetic Input Field OK
0	1	Distance increase (Push-Release)
1	0	Distance decrease (Push-Fn)
1	1	Magnetic Input Field invalid – out of range too large, too small (Missing magnet)

Table 3: Magnetic magnitude variation indicator

Note: Pin 1 (MagINCn) and Pin 2 (MagDECn) are active low via open drain output.

The absolute angular output is always set to a resolution of 10 bit. Placing the magnet above the chip, angular values increase in clockwise direction by default.

Data D0:D0 is valid, when the status bits have the following configurations:

OCF	COF	LIN	Mag INC	Mag DEC	Parity
1	0	0	0	0	even checksum of bits 1:13
			0	1	
			1	0	

Table 4: status bit outputs

The absolute angular position is sampled at a rate of 10 kHz (0.1ms). This allows reading out all 1024 positions per 360 degrees within 0.1 seconds (9.76 Hz) without skipping any position. By multiplying 10Hz by 60, one obtains the corresponding maximum rotational speed of 585.9 rpm.

If skipping every second absolute angular position would be acceptable for specific applications, one could increase the rotational speed of the magnet source by a factor of two. Thus speeds of 1200 rpm would be achievable.

Readout of every absolute angular position allows for rotational speeds of up to 600rpm

Readout of every second angular position allows for rotational speeds of up to 1200rpm

Consequently increasing the rotational speed diminishes the number of absolute angular positions to be read out (see Table 6). Regardless of the rotational speed or the number of positions to be read out, the absolute angular value is always given at the highest resolution of 10-bit.

The incremental outputs are not affected by rotational speed restrictions due to the implemented interpolator. The incremental output signals may be used for high-speed applications with rotational speeds of up to 10,000rpm without missing pulses.

## 10bit Pulse Width Modulation Output

The AS5040 provides a pulse width modulated output (PWM), whose duty cycle is proportional to the measured angle:

$$Position = \frac{t_{on} \cdot 1025}{(t_{on} + t_{off})} - 1$$

The PWM frequency is internally trimmed to an accuracy of  $\pm 5\%$ . This tolerance can be cancelled by measuring the complete duty cycle as shown above.

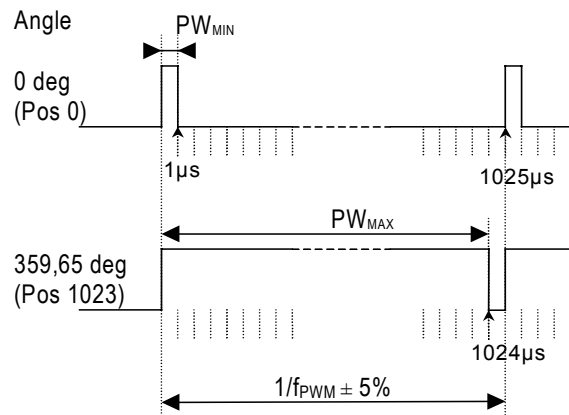


Figure 5: PWM output signal

Parameter	Symbol	Typ	Unit	Note
PWM frequency	$f_{PWM}$	0.9756	kHz	Signal period: 1025 $\mu$ s
MIN pulse width	$PW_{MIN}$	1	$\mu$ s	- Position 0d - Angle 0 deg
MAX pulse width	$PW_{MAX}$	1024	$\mu$ s	- Position 1023d - Angle 359,65 deg

Table 5: PWM signal parameters

## Generating an Analog Output

This can be achieved by averaging the PWM signal, using an external active or passive low pass filter.

This method generates an analogue output signal that is proportional to the measured angle. Thus the device can be used as direct replacement of potentiometers with an analogue voltage output.

## Incremental Outputs

Three different incremental output modes are possible with Quadrature A/B being the default mode.

Figure 6 shows the two-channel quadrature as well as the single channel incremental signal (LSB) and the direction bit in clockwise (CW) and counter-clockwise (CCW) direction.

## Quadrature A / B Output (quad AB Mode)

The phase shift between channel A and B indicates the direction of the magnet movement. Channel A leads channel B at a clockwise rotation of the magnet (top view, magnet placed above or below the device) with 90 electrical degrees. Channel B leads channel A at a counter-clockwise rotation.

### Single Channel Output (LSB / Dir Mode)

Output LSB reflects the LSB (least significant bit) of the actual programmed incremental resolution (OTP Register Bit Div0, Div1). Output Dir provides information about the rotational direction of the magnet, which may be placed above or below the device (1=clockwise; 0=counterclockwise; top view). Dir is updated with every LSB change.

In both modes (quad A/B, single channel) the resolution and the index output are user programmable. The index pulse indicates the zero position and is by default one angular step (1LSB) wide. However, it can be set to three LSBs by programming the Index-bit of the OTP-Register accordingly (see Table 7).

### High Speed Operation

#### Absolute mode:

The AS5040 has an internal sampling rate of 10kHz. Consequently, it will sample the angle of the magnet every 100µs. Given this value, for a magnet rotating at high speed, the number of samples (n) per turn can be calculated by

$$n = \frac{60}{rpm \cdot 100\mu s}$$

In practice, there is no upper speed limit. The only restriction is that there will be fewer samples per revolution as the speed increases.

Regardless of the rotational speed, the absolute angular value is always sampled at the highest resolution of 10-bit.

#### Incremental mode:

Incremental encoders are usually required to produce NO missing pulses up to several thousand rpm's.

Therefore, the AS5040 has a built-in interpolator, which ensures that there are no missing pulses at the incremental outputs for rotational speeds of up to 10,000 rpm, even at the highest resolution of 10bits (256 pulses per revolution).

Absolute Output Mode	Incremental Output Mode
586 rpm = 1024 samples / turn	no missing pulses @ 10bit resolution (256ppr): max. speed = 10,000 rpm
1172 rpm = 512 samples / turn	
2343 rpm = 256 samples / turn	
etc...	

Table 6: Speed performance

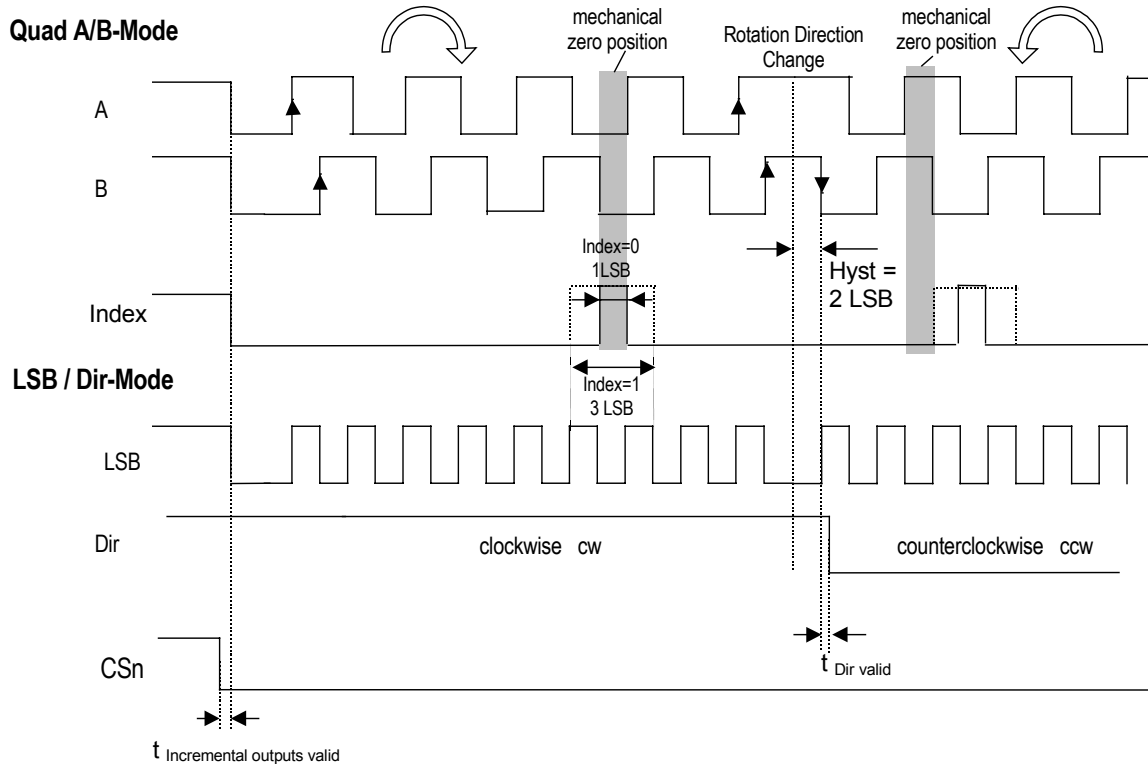


Figure 6: Incremental Output Modes

### Incremental output hysteresis

To avoid flickering incremental outputs at a stationary magnet position, a hysteresis is introduced.

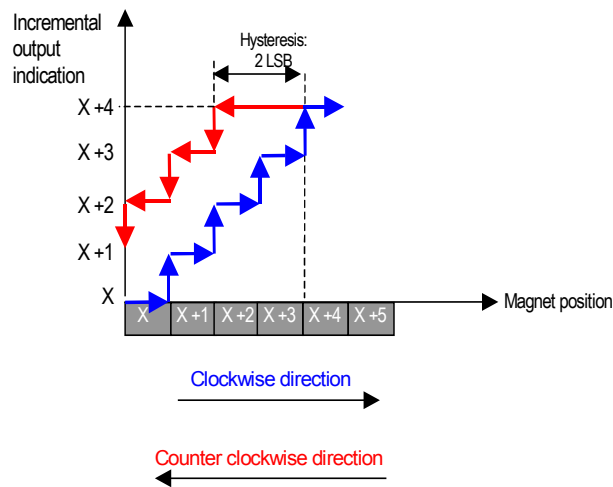


Figure 7: Hysteresis window for incremental outputs

In case of any change of the rotational direction, the incremental outputs have a hysteresis of 2 LSB (1LSB upon request).

Regardless of the programmed incremental resolution, the hysteresis of 2 LSB always corresponds to the highest resolution of 10 bit. In absolute terms, the hysteresis is set to 0.704 degrees.

For constant rotational directions, every magnet position change is indicated at the incremental outputs (Figure 7). If for example the magnet turns clockwise from position „x+3“ to „x+4“, the incremental output would also indicate this position accordingly.

A change of the magnet’s rotational direction back to position „x+3“ means, that the incremental output still remains unchanged for the duration of 2 LSB, until position „x+2“ is reached. After this transition, the incremental outputs directly indicate every new position, while the rotational direction is constant.

### Daisy Chain Mode

It is possible to connect several AS5040’s in series, while reading them by just one serial data line. This so-called “daisy-chain” mode is accomplished by connecting the data output (DO; pin 9) to the data input (PROG; pin 8) of the subsequent device. The serial data of all connected devices is read from the DO pin of the last device in the chain. The length of the serial bit stream increases with every connected device, it is

$n \times (16+1)$  bits:

e.g 34bit for two devices, 51bit for three devices,etc...

The last data bit of the first device (Parity) is followed by a logic "0" and the first data bit of the second device (D9), etc..

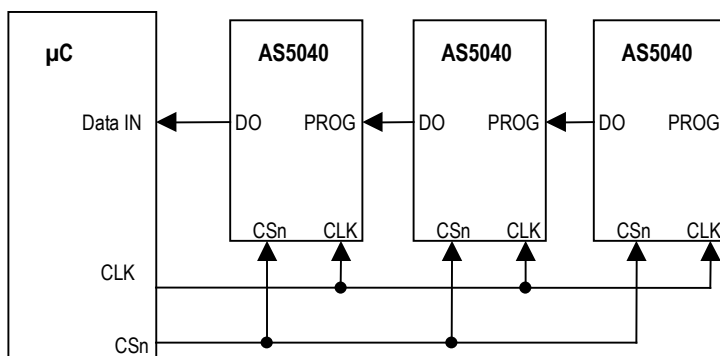


Figure 8: Daisy Chain Mode configuration

### Brush-less DC Motor Commutation Mode

Brush-less DC motors require angular information for current commutation purposes. The AS5040 provides U-V-W commutation signals for one and two pole pair motors. In addition to the three-phase output signals the single channel (LSB) output at pin 12 allows high accuracy speed measurement. Two resolutions (9 or 10 bit) can be selected by programming Div0 according to Table 7.

Mode 3.0 (3.1) is used for brush-less DC motors with one pole pair rotors. The three phases (U,V,W) are 120 degrees apart, each phase is 180 degrees on and 180 degrees off.

Mode 3.2 (3.3) is used for motors with two pole pairs requiring a higher pulse count to ensure a proper current commutation. In this case the pulse width is 256 positions, equal to 90 degrees.

The precise physical angle at which the U, V and W signals change state ("Angle" in Figure 9 and Figure 10) is calculated by multiplying each transition position by the angular value of 1 count:

$$\text{Angle [deg]} = \text{Position} \times (360 \text{ degree} / 1024)$$

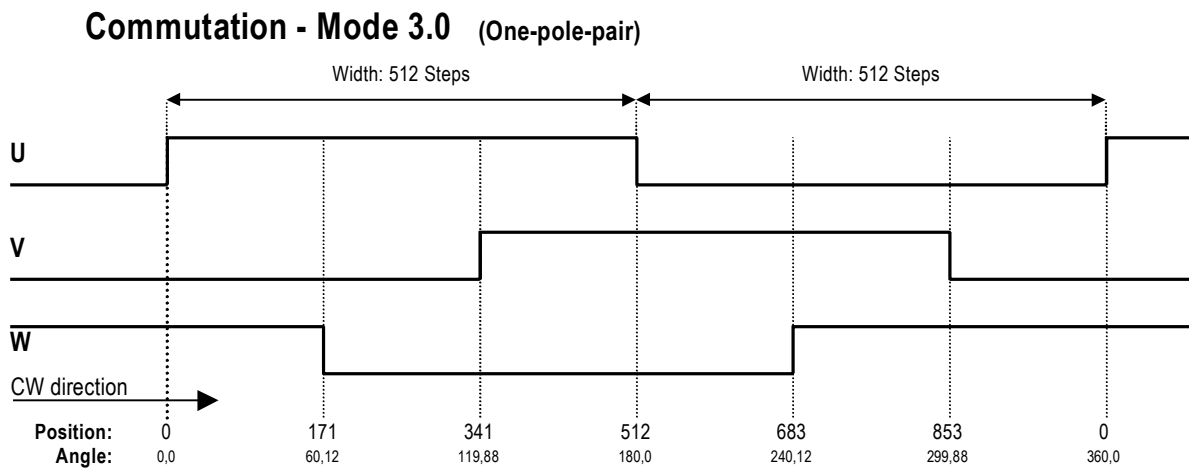


Figure 9: U, V and W-signals for BLDC motor commutation (Div1 = 0; Div0 = 0)

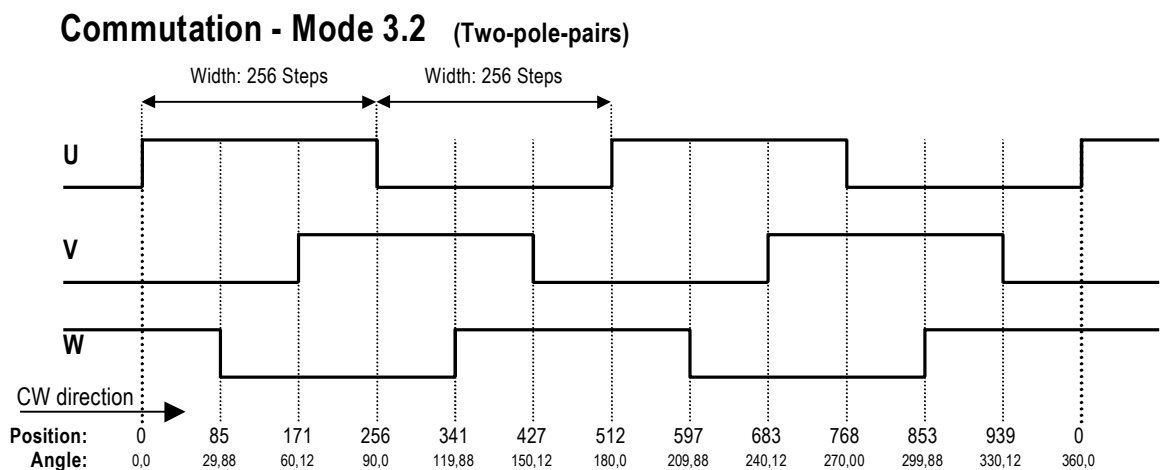


Figure 10: U, V and W-signals for 2 pole BLDC motor commutation (Div1=1; Div0 = 0)



## Programming the AS5040

After power-on, programming the AS5040 is enabled at the rising edge of CSn with Prog = logic high. 16 bit configuration data must be serially written into the OTP register via the Prog-pin. The first "CCW" bit is followed by the zero position data (MSB first) and the Incremental Mode setting. Data must be valid at the rising edge of CLK (Figure 11).

After writing the data into the OTP register it can be permanently programmed ("zapped") by rising the Prog pin to the programming voltage  $V_{PROG}$ . 16 accurate CLK pulses ( $t_{PROG}$ ) must be applied to program the fuses (Figure 12). The programmed data is available after the next power-on.

### OTP Register Content:

<b>CCW</b>	Counter Clockwise Bit
CCW=0	angular value increases in clockwise direction
CCW=1	angular value increases in counter clockwise direction
<b>Z [9:0]</b>	Programmable Zero / Index Position
<b>Indx</b>	Index Pulse Width Selection
<b>Div1, Div0</b>	Divider Setting of Incremental Output
<b>Md1, Md0</b>	Incremental Output Mode Selection

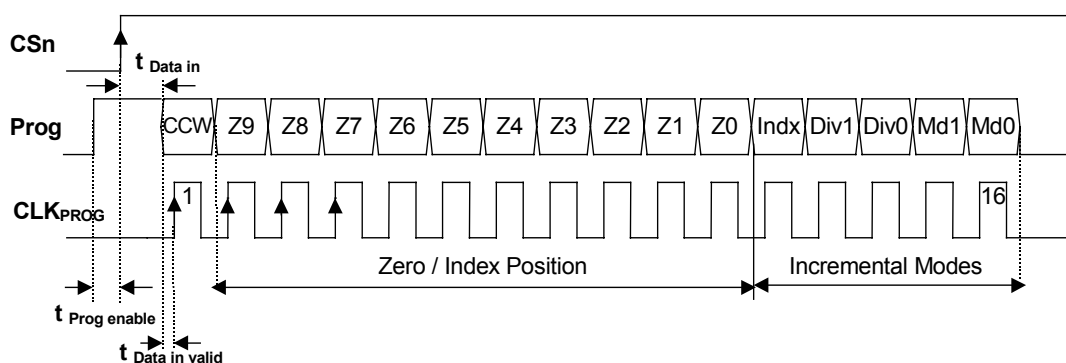


Figure 11: Programming Access – Write Data

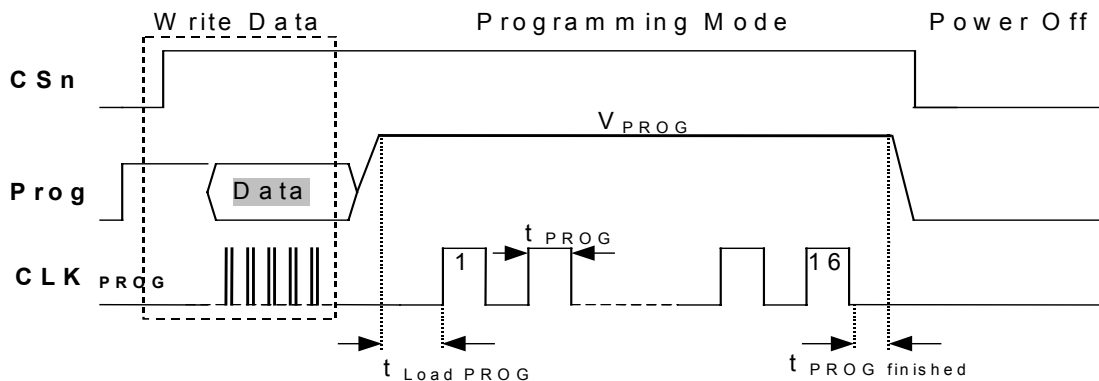


Figure 12: Programming Access – Zapp Data

## Zero Position Programming

Any 10bit angular position can be defined as the zero/index position. It may be used in several applications in order to simplify assembly. For Zero Position Programming, the magnet must be brought to the mechanical zero position of the system (e.g. the "off"-position of a rotary switch). The orientation (north/south pole) of the magnet does not need to be considered.

The mechanical zero position can be read out via the SSI and be assigned as new zero position Z[9:0] and programmed into the OTP register.

This new absolute zero position at the same time also represents the Index pulse position for incremental output modes.

## Incremental Mode Programming

Three different incremental output modes are available.

Mode: Md1=0 / Md0=1 sets the AS5040 in quadrature mode.

Mode: Md1=1 / Md0=0 sets the AS5040 in single channel mode with direction indicator (see **Table 1**)

In both modes the incremental resolution can be reduced from 10 bit down to 9, 8 or 7 bit using the divider OTP bits Div1 and Div0. Md0 or Md1 must additionally set for that purpose.

Mode: Md1=1 / Md0=1 sets the AS5040 in brushless DC motor commutation mode with an additional LSB incremental signal at pin 12 (PWM\_LSB).

To allow programming of all bits, the default factory setting is all bits = 0. This mode is equal to mode 1:0 (quadrature AB, 1LSB index width, 256ppr).

The absolute angular output value, by default, increases if the magnet, placed either above or below the chip, turns clockwise (top view). Setting the CCW-bit (see

Figure 11) allows for reversing the indicated direction, e.g. when the magnet is placed underneath the IC. (CCW = 0 - angular value increases clockwise; CCW = 1 - angular value increases counter clockwise).

By default, the zero / index position pulse is one LSB wide. However, it can be increased to a three LSB wide pulse by setting the Index-bit of the OTP Register. This is especially useful for high speed operation, where the index signal output may be just a small glitch otherwise.

Especially for brush-less DC motor-control, further programmable options are available (Commutation-Modes), are available. Md1 = Md0 = 1 changes the incremental output pins 3,4 and 6 to a 3-phase commutation signal. Div1 defines the number of pulses per revolution for either a single-pole (Div1=0) or two-pole pair (Div1=1) motor operation. In addition, the LSB is available at pin 12 (the LSB signal replaces the PWM-signal), which allows for high rotational speed measurement of up to 10,000 rpm.

Mode	OTP-Mode-Register-Bit					PIN #				Pulses per Incremental Revolution Resolution	
	Md1	Md0	Div1	Div0	Index	3	4	6	12	ppr	bit
Default (Mode0.0)	0	0	0*	0*	0*	A	B	1LSB	PWM 10bit	2x256	10
quadAB-Mode1.0	0	1	0	0	0			1LSB			
quadAB-Mode1.1	0	1	0	0	1			3LSBs			
quadAB-Mode1.2	0	1	0	1	0			1LSB		2x128	9
quadAB-Mode1.3	0	1	0	1	1			3LSBs			
quadAB-Mode1.4	0	1	1	0	0			1LSB			
quadAB-Mode1.5	0	1	1	0	1			3LSBs		2x64	8
quadAB-Mode1.6	0	1	1	1	0			1LSB			
quadAB-Mode1.7	0	1	1	1	1			3LSBs			
LSB/Dir-Mode2.0	1	0	0	0	0	LSB	Dir	1LSB	PWM 10bit	512	10
LSB/Dir-Mode2.1	1	0	0	0	1			3LSBs			
LSB/Dir -Mode2.2	1	0	0	1	0			1LSB		256	9
LSB/Dir -Mode2.3	1	0	0	1	1			3LSBs			
LSB/Dir -Mode2.4	1	0	1	0	0			1LSB			
LSB/Dir -Mode2.5	1	0	1	0	1			3LSBs		128	8
LSB/Dir -Mode2.6	1	0	1	1	0			1LSB			
LSB/Dir -Mode2.7	1	0	1	1	1			3LSBs			
Commutation-Mode3.0	1	1	0	0	0	U(0°)	V(120°)	W(240°)	LSB	3 x 1	10
Commutation-Mode3.1	1	1	0	1	0						9
Commutation-Mode3.2	1	1	1	0	0	U' (0°, 180°)	V' (60°, 240°)	W' (120°, 300°)	LSB	2 x 3	10
Commutation-Mode3.3	1	1	1	1	0						9

Table 7: One Time Programmable (OTP) register options

\*Note: Div1, Div0 and Index cannot be programmed in Mode 0:0

## Alignment Mode

The alignment mode simplifies centering the magnet over the center of the chip to gain maximum accuracy.

Alignment mode can be enabled with the falling edge of CSn while PROG = logic high (Figure 13). The Data bits D9-D0 of the SSI change to a 10bit displacement amplitude output. The magnet is properly aligned, when the reading is  $\leq 32$  at all rotation angles. The larger the value, the further the magnet is off-center at that particular angle.

The MagINCn and MagDECn indicators will be = 1 when the alignment mode reading is  $> 32$ . A properly aligned magnet will produce a  $\text{MagINCn} = \text{MagDECn} = 0$  signal throughout a full 360° turn of the magnet.

The Alignment mode can be reset to normal operation mode by a power-on-reset (disconnect / re-connect power supply).

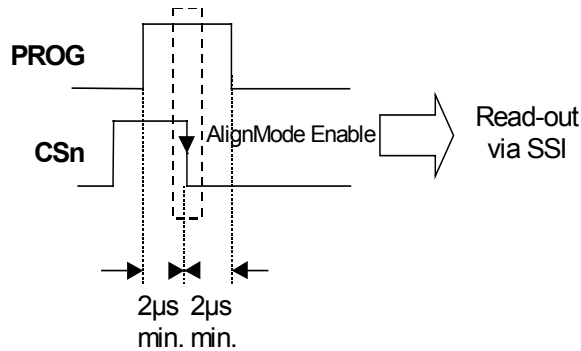


Figure 13: Enabling the alignment mode

## 3.3V / 5V Operation

The AS5040 operates either at 3.3V  $\pm 10\%$  or at 5V  $\pm 10\%$ . This is made possible by an internal 3.3V Low-Dropout (LDO) Voltage regulator. The internal supply voltage is always taken from the output of the LDO, meaning that the internal blocks are always operating at 3.3V.

For 3.3V operation, the LDO must be bypassed by connecting VDD3V3 with VDD5V (see Figure 14).

For 5V operation, the 5V supply is connected to pin VDD5V, while VDD3V3 (LDO output) must be buffered by a 1...10µF capacitor, which is supposed to be placed close to the supply pin (see Figure 14).

The VDD3V3 output is intended for internal use only. It must not be loaded with an external load.

The output voltage of the digital interface I/O's corresponds to the voltage at pin VDD5V, as the I/O buffers are supplied from this pin (see Figure 14).

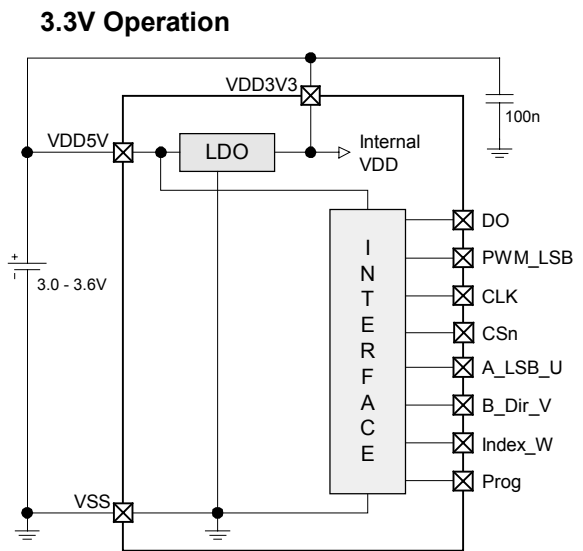
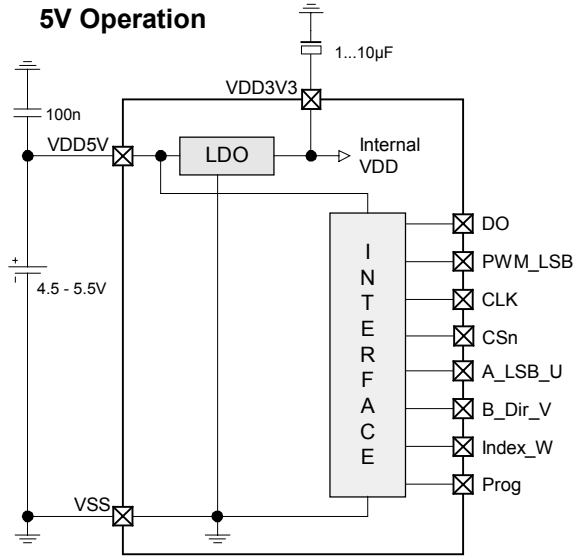


Figure 14: Connections for 5V / 3.3V supply voltages

A buffer capacitor of 100nF is recommended in both cases close to pin VDD5V.

### Choosing the proper magnet

Typically the magnet should be 6mm in diameter and 3mm in height. Magnetic materials such as rare earth AlNiCo/SmCo5 or NdFeB are recommended.

The magnetic field strength perpendicular to the die surface has to be in the range of  $\pm 45\text{mT} \dots \pm 75\text{mT}$  (peak).

The magnet's field strength should be verified using a gauss-meter. The magnetic field  $B_v$  at a given distance, along a concentric circle with a radius of 1.1mm ( $R_1$ ), should be in the range of  $\pm 45\text{mT} \dots \pm 75\text{mT}$ . (see Figure 15).

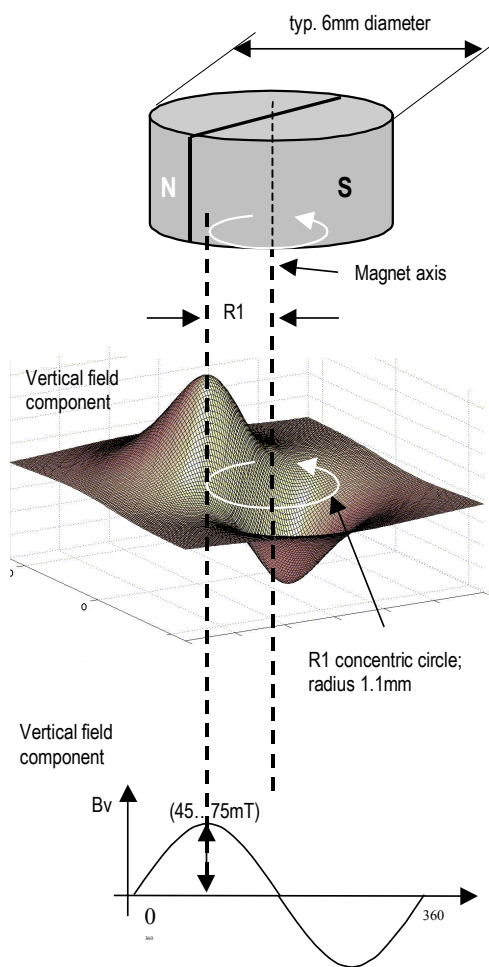


Figure 15: Typical magnet (6x3mm) and magnetic field distribution

### Physical Placement of the Magnet

The best linearity can be achieved by placing the magnet according to the drawing below.

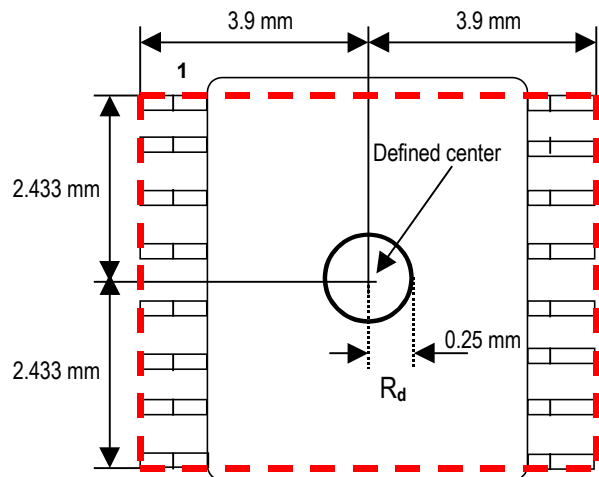


Figure 16: Defined center and displacement radius  $R_d$

#### Magnet placement:

The magnet's axis should be aligned within a radius  $R_d$  of 0.25mm (displacement radius  $R_d$ ) with respect to 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 (see Figure 15). The typical distance "z" between the magnet and the package surface is 0.5 mm to 1.5mm, 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 MagINCn (pin 1) and MagDECn (pin 2), see Table 2.

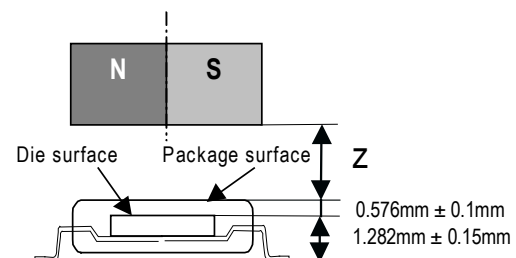


Figure 17: Vertical placement of the magnet

## Electrical Characteristic

### Absolute Maximum Ratings (non operating)

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.

Parameter	Symbol	Min	Max	Unit	Note
DC supply voltage at pin VDD5V	VDD5V	-0.3	7	V	
DC supply voltage at pin VDD3V3	VDD3V3		5	V	
Input pin voltage	V <sub>in</sub>	-0.3	VDD5V +0.3	V	
Input current (latchup immunity)	I <sub>scr</sub>	-100	100	mA	Norm: Jedec 17
Electrostatic discharge	ESD	± 1		kV	Norm: MIL 883 E method 3015
Storage temperature	T <sub>stg</sub>	-55	125	°C	Min – 67°F ; Max +257°F
Body temperature (Lead-free package)	T <sub>Body</sub>		250	°C	t=20 to 40s, Norm: IPC/JEDEC J-Std-020B Lead finish 100% Sn "matte tin"
Humidity non-condensing	H	5	85	%	

### Operating Conditions

Parameter	Symbol	Min	Typ	Max	Unit	Note
Ambient temperature	T <sub>amb</sub>	-40		125	°C	-40°F...+257°F
Supply current	I <sub>supp</sub>		16	25	mA	
Supply voltage at pin VDD5V	VDD5V	4.5	5.0	5.5	V	5V Operation
Voltage regulator output voltage at pin VDD3V3	VDD3V3	3.0	3.3	3.6	V	
Supply voltage at pin VDD5V	VDD5V	3.0	3.3	3.6	V	3.3V Operation (pin VDD5V and VDD3V3 connected)
Supply voltage at pin VDD3V3	VDD3V3	3.0	3.3	3.6	V	

### DC Characteristics for Digital Inputs and Outputs

CMOS Schmitt-Trigger Inputs: CLK, CS<sub>n</sub>. (CS<sub>n</sub>= internal Pull-up)

Parameter	Symbol	Min	Max	Unit	Note
High level input voltage	V <sub>IH</sub>	0.7 * VDD5V		V	normal operation
Low level input voltage	V <sub>IL</sub>		0.3 * VDD5V	V	
Schmitt Trigger hysteresis	V <sub>Ion</sub> - V <sub>Ioff</sub>	1		V	
Input leakage current	I <sub>LEAK</sub>	-1	1	µA	CLK only
Pullup low level input current	I <sub>IL</sub>	-30	-100	µA	CS <sub>n</sub> only, VDD5V: 5.0V

### CMOS / Program Input: Prog

Parameter	Symbol	Min	Max	Unit	Note
High level input voltage	V <sub>IH</sub>	0.7 * VDD5V	5	V	
High level input voltage	V <sub>PROG</sub>	see "programming conditions"		V	during programming
Low level input voltage	V <sub>IL</sub>		0.3 * VDD5V	V	
Pulldown high level input current	I <sub>IL</sub>		100	µA	VDD5V: 5.5V

**CMOS Output Open Drain: MagINCn, MagDECn**

Parameter	Symbol	Min	Max	Unit	Note
Low level output voltage	$V_{OL}$		VSS+0.4	V	
Output current	$I_o$		4 2	mA	VDD5V: 4.5V VDD5V: 3V
Open drain leakage current	$I_{oz}$		1	$\mu$ A	

**CMOS Output: A, B, Index, PWM**

Parameter	Symbol	Min	Max	Unit	Note
High level output voltage	$V_{OH}$	VDD5V-0.5		V	
Low level output voltage	$V_{OL}$		VSS+0.4	V	
Output current	$I_o$		4 2	mA mA	VDD5V: 4.5V VDD5V: 3V

**Tristate CMOS Output: DO**

Parameter	Symbol	Min	Max	Unit	Note
High level output voltage	$V_{OH}$	VDD5V -0.5		V	
Low level output voltage	$V_{OL}$		VSS+0.4	V	
Output current	$I_o$		4 2	mA mA	VDD5V: 4.5V VDD5V: 3V
Tri-state leakage current	$I_{oz}$		1	$\mu$ A	

**Magnetic Input Specification**

Two-pole cylindrical diametrically magnetised source:

Parameter	Symbol	Min	Max	Unit	Note
Diameter	$d_{mag}$	4		mm	Recommended diameter: 6mm
Magnetic input field amplitude	$B_{pk}$	45	75	mT	Required vertical component of the magnetic field strength on the die's surface, measured along a concentric circle with a radius of 1.1mm
Magnetic offset	$B_{off}$		$\pm 5$	mT	Constant magnetic stray field
Field non-linearity			5	%	Including offset gradient
Input frequency (rotational speed of magnet)	$f_{mag\_abs}$		10	Hz	Absolute mode: 600 rpm @ readout of 1024 positions (see table 6)
	$f_{mag\_inc}$		166	Hz	Incremental mode: no missing pulses at rotational speeds of up to 10,000 rpm (see table 6)
Magnetic field temperature drift	$B_{tc}$		typ. - 0.035	%/K	Samarium Cobalt ReComa28
Displacement radius	Disp		0.25	mm	Max. offset between defined device center and magnet axis (see Figure 16)

## Electrical System Specifications

Parameter	Symbol	Min	Typ	Max	Unit	Note
Resolution	RES			10	bit	0.352 deg
7 bit			2.813		deg	Adjustable resolution only available for incremental output modes; Least significant bit, minimum step
8 bit			1.406			
9 bit			0.703			
10 bit			0.352			
Integral non-linearity (optimum)	INL <sub>opt</sub>			± 0.5	deg	Maximum error with respect to the best line fit. Verified at optimum magnet placement @ 25 °C.
Integral non-linearity	INL			± 1.4	deg	Best line fit = $(Err_{max} - Err_{min}) / 2$ Over displacement tolerance and full operating temperature range with 6mm diameter magnet
Differential non-linearity	DNL			± 0.176	deg	10bit no missing codes
Transition noise	TN			0.12	Deg RMS	RMS equivalent to 1 sigma
Hysteresis	Hyst		0.704		deg	0.352 deg (1 LSB) hysteresis available upon request
Power-on reset thresholds						
On Voltage; 300mV typ. Hysteresis	V <sub>on</sub>	1.37	2.2	2.9	V	DC supply voltage 3.3V (VDD3V3)
Off Voltage; 300mV typ. Hysteresis	V <sub>off</sub>	1.08	1.9	2.6	V	DC supply voltage 3.3V (VDD3V3)
Power-up time	t <sub>PwrUp</sub>	100		400 *	ms	*...Until offset compensation finished
System propagation delay absolute output	t <sub>delay</sub>			65	µs	Includes delay of ADC, DSP, absolute interface
System propagation delay incremental output				200	µs	Calculation over two samples
Sampling rate for absolute output	f <sub>s</sub>	9.5	10	10.5	kHz	Internal sampling rate
Read-out frequency	CLK			1	MHz	Max. clock frequency to read out serial data

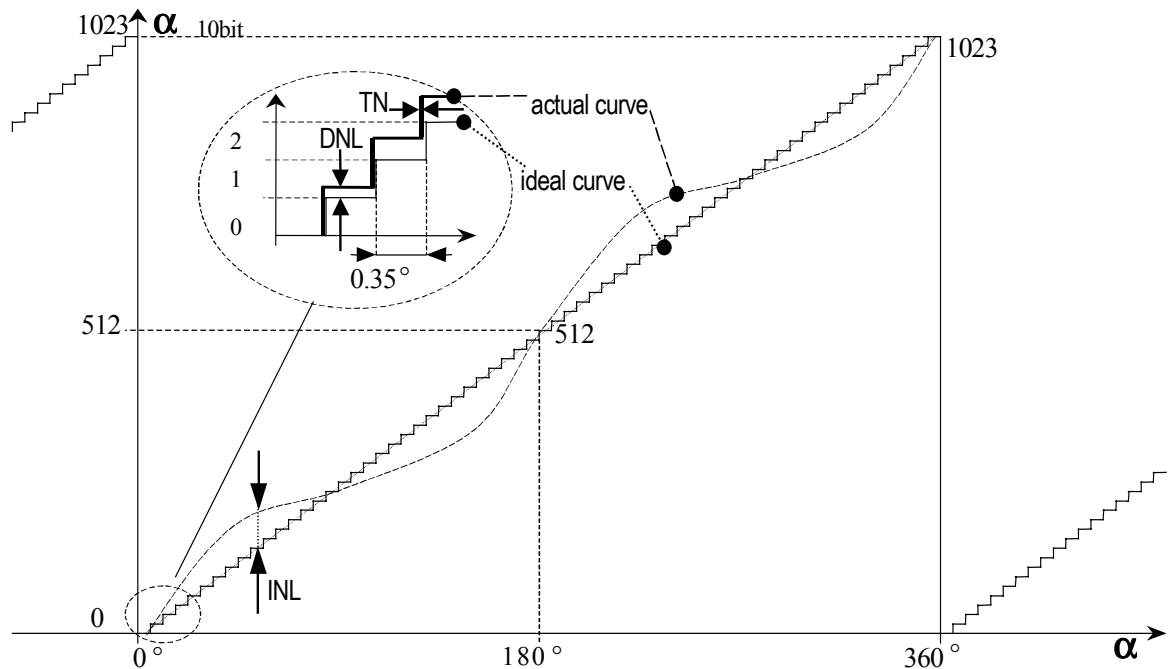


Figure 18: Integral and differential Non-Linearity (example)

Integral Non-Linearity (INL) is the maximum deviation between actual position and indicated position

Differential Non-Linearity (DNL) is the maximum deviation of the step length from one position to the next

Transition Noise (TN) is the repeatability of an indicated position

## Timing Characteristics

### Synchronous Serial Interface (SSI)

Parameter	Symbol	Min	Typ	Max	Unit	Note
Data output activated (logic high)	$t_{DO\ active}$			100	ns	Time between falling edge of CSn and data output activated
First data shifted to output register	$t_{CLK\ FE}$	500			ns	Time between falling edge of CSn and first falling edge of CLK
Start of data output	$T_{CLK/2}$	500			ns	Rising edge of CLK shifts out one bit at a time
Data output valid	$t_{DO\ valid}$			375	ns	Time between rising edge of CLK and data output valid
Data output tristate	$t_{DO\ tristate}$			100	ns	After the last bit DO changes back to "tristate"
Pulse width of CSn	$t_{CSn}$	500			ns	CSn = high; To initiate read-out of next angular position
Read-out frequency	$f_{CLK}$	>0		1	MHz	Clock frequency to read out serial data

### Pulse Width Modulation Output

Parameter	Symbol	Min	Typ	Max	Unit	Note
PWM frequency	$f_{PWM}$	0.927	0.976	1.024	KHz	Signal period = 1025 $\mu$ s $\pm$ 5%
Minimum pulse width	$PW_{MIN}$	0.95	1	1.05	$\mu$ s	Position 0d; Angle 0 degree
Maximum pulse width	$PW_{MAX}$	973	1024	1075	$\mu$ s	Position 1023d; Angle 359.65 degree

### Incremental Outputs

Parameter	Symbol	Min	Typ	Max	Unit	Note
Incremental outputs valid after power-up	$t_{Incremental\ outputs\ valid}$			500	ns	Time between first falling edge of CSn after power-up and valid incremental outputs
Directional indication valid	$t_{Dir\ valid}$			500	ns	Time between rising or falling edge of LSB output and valid directional indication

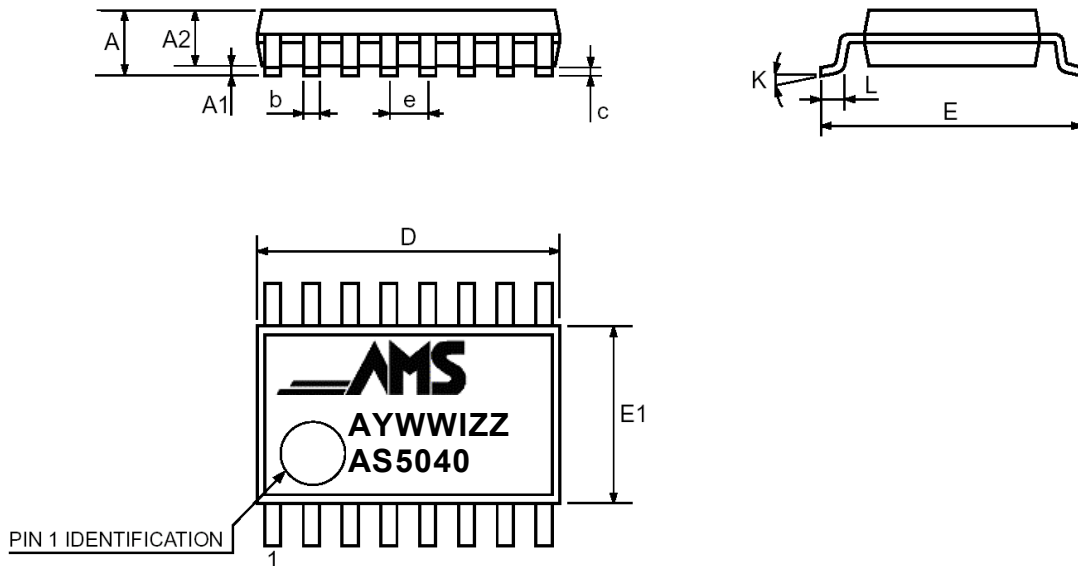
## Programming Conditions

Parameter	Symbol	Min	Typ	Max	Unit	Note
Programming enable time	$t_{Prog\ enable}$	2			$\mu$ s	Time between rising edge at Prog pin and rising edge of CSn
Write data start	$t_{Data\ in}$	2			$\mu$ s	
Write data valid	$t_{Data\ in\ valid}$	250			ns	Write data at the rising edge of CLK <sub>PROG</sub>
Load Programming data	$t_{Load\ PROG}$	2			$\mu$ s	
Write data – programming CLK <sub>PROG</sub>	CLK <sub>PROG</sub>			250	kHz	
CLK pulse width	$t_{PROG}$	1.8	2	2.2	$\mu$ s	during programming; 16 clock cycles
Hold time of V <sub>prog</sub> after programming	$t_{PROG\ finished}$	2			$\mu$ s	Programmed data is available after next power-on
Programming voltage	V <sub>PROG</sub>	7.3	7.4	7.5	V	Must be switched off after zapping
Programming current	I <sub>PROG</sub>			130	mA	during programming



## Package Drawings and Markings

16-Lead Shrink Small Outline Package SSOP-16



Dimensions						
Symbol	mm			inch		
	min.	typ.	max	min.	typ.	max.
A	1.73	1.86	1.99	.068	.073	.078
A1	0.05	0.13	0.21	.002	.005	.008
A2	1.68	1.73	1.78	.066	.068	.070
b	0.25	0.315	0.38	.010	.012	.015
c	0.09	-	0.20	.004	-	.008
D	6.07	6.20	6.33	.239	.244	.249
E	7.65	7.8	7.9	.301	.307	.311
E1	5.2	5.3	5.38	.205	.209	.212
e	0.65			.0256		
K	0°	-	8°	0°	-	8°
L	0.63	0.75	0.95	.025	.030	.037

### Marking: AYWWIZZ

A:Pb-Free Identifier

Y:Last Digit of Manufacturing Year

WW: Manufacturing Week

I: Plant Identifier

ZZ: Traceability Code

JEDEC Package Outline Standard:

MO - 150 AC

Thermal Resistance  $R_{th(j-a)}$ :

151 K/W

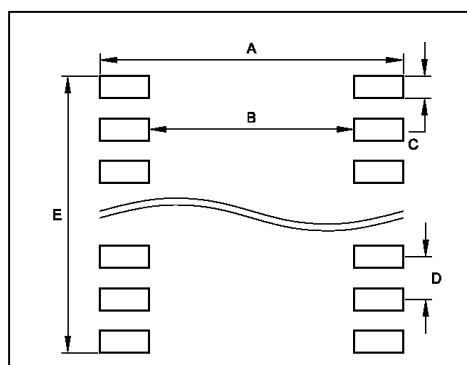
IC's marked with a white dot or the letters "ES" denote Engineering Samples

## Ordering Information

Delivery: Tape and Reel (1 reel = 2000 devices)  
Tubes (1 box = 100 tubes á 77 devices)

Order # 12817-002 for delivery in tubes

Order # 12817-202 for delivery in tape and reel

**Recommended PCB footprint:**

recommended footprint data		
	mm	inch
A	9.02	0.355
B	6.16	0.242
C	0.46	0.018
D	0.65	0.025
E	5.01	0.197

**Revision History**

Revision	Date	Description
1.0	April. 2, 2004	updated Fig.7 added Fig.8 : Daisy Chain Mode
1.1	Jun. 11, 2004	combine Vzapp = Vprog add Fig.18: INL / DNL example DC characteristics: remove absolute schmitt trigger input thresholds Timing characteristics: add Fclk min change max. power-up time change programming characteristics: $t_{Load\ PROG}$ , $CLK\ PROG$ add package outlines and markings add definition of parity bit add description of high speed operation for absolute mode change $t_{DInvalid}$

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