AS5040

10 BIT PROGRAMMABLE MAGNETIC ROTARY ENCODER

PRELIMINARY DATA SHEET

Key Features

- 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
- Absolute angular position mode:
  - 10-bit resolution providing 1024 absolute positions per 360 degrees (step size ~ 0.35 deg)
  - Quadrature A/B and index output signal
  - Single channel output and direction indication
  - U-V-W commutation signals
- Synchronous serial interface (SSI) output
- Pulse width modulated (PWM) output
- User programmable zero / index position
- Failure detection mode for magnet placement monitoring
- Rotational speeds up to 10,000 rpm (incremental output)
- Push button functionality
- Two supply voltages: 3.3 V or 5 V
- Wide temperature range: - 40°C to + 125°C
- SSOP 16 package (5.3mm x 6.2mm)

Benefits

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

Applications

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

General Description

The AS5040 is a system-on-chip, combining integrated Hall elements 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.

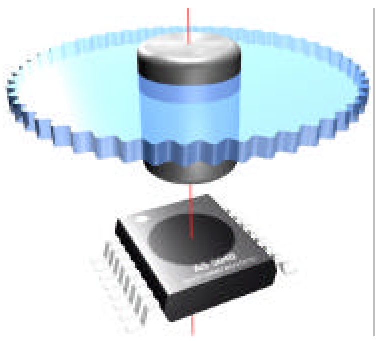

Figure 1 Typical arrangement AS5040 and magnet

Pin Configuration

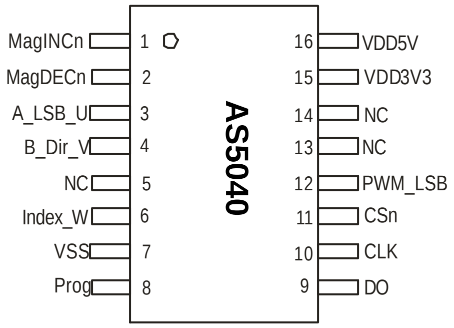

Figure 2 Pin configuration SSOP16

Pin Description

Table 1 shows the description of each pin of the standard SSOP16 package (Shrink Small Outline Package, 16 leads, body size: 5.3mm x 6.2mmm; 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:

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.

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 OTP-ROM.

Pin 9 represents the data output (DO) and Pin 10, the clock (CLK) input of the Synchronous Serial Interface (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.

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) µs). 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.

Pin	Symbol	Type	Description
1	MagINCn	DO_OD	Magnet Field **Mag**nitude **INC**rease; active low, indicates a distance reduction between the magnet and the device surface.
2	MagDECn	DO_OD	Magnet Field **Mag**nitude **DEC**rease; active low, indicates a distance increase between the device and the magnet.
3	A_LSB_U	DO	*Mode1:* Quadrature **A** channel *Mode2:* **L**east **S**ignificant **B**it *Mode3:* **U** signal (phase1)
4	B_Dir_V	DO	*Mode1*: Quadrature **B** channel quarter period shift to channel A. *Mode2:* **Dir**ection of Rotation *Mode3:* **V** signal (phase2)
5	NC	-	not connected
6	Index_ W	DO	*Mode1 and Mode2* : **Index** signal indicates the absolute zero position *Mode3*: **W** signal (phase3)
7	VSS	S	Negative Supply Voltage (GND)
8	Prog	DI_PD	**Prog**ramming and Data Input for Mode configuration, incremental resolution setting, Zero-Position Programming and Daisy Chain mode configuration.
9	DO	DO_T	**D**ata **O**utput of Synchronous Serial Interface
10	CLK	DI	**Cl**oc**k** Input of Synchronous Serial Interface
11	CSn	DI_PU	**C**hip **S**elect, active low
12	PWM_LSB	DO	**P**ulse **W**idth **M**odulation of approx. 1kHz; **LSB** in *Mode3*
13	NC	-	Not connected
14	NC	-	Not connected
15	VDD3V3	S	3V-Regulator Output
16	VDD5V	S	Positive Supply Voltage 5 V

Table 1 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		

Note: Pins 5, 13 and 14 must be not be connected

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 centre of the device and deliver the voltage representation of the magnetic field.

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 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.

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 the Pulse Width Modulation (PWM) This PWM signal output also allows the generation of a direct proportional analogue voltage, by using an external Low-Pass-Filter.

Beside the absolute angular position signals the device provides incremental output signals at the same time. The various incremental output modes can be selected by programming the OTP mode register bits according to table 5. 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.

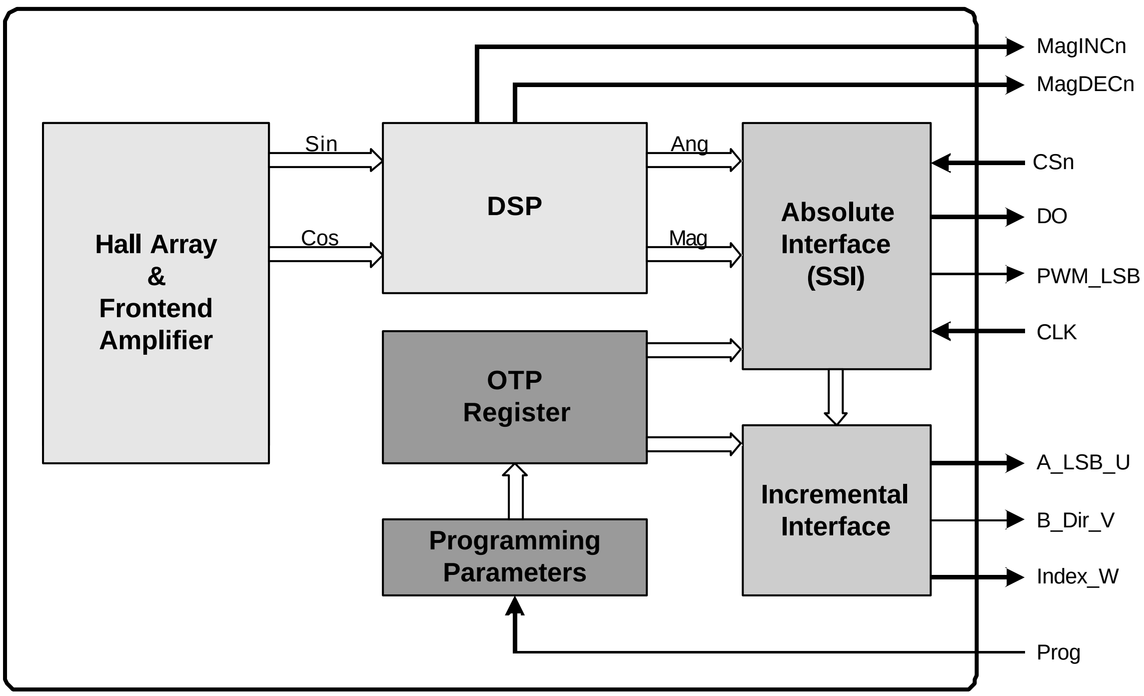

Figure 3 A5040 Block Diagram

10 bit Absolute Angular Position Output

Synchronous Serial Interface SSI

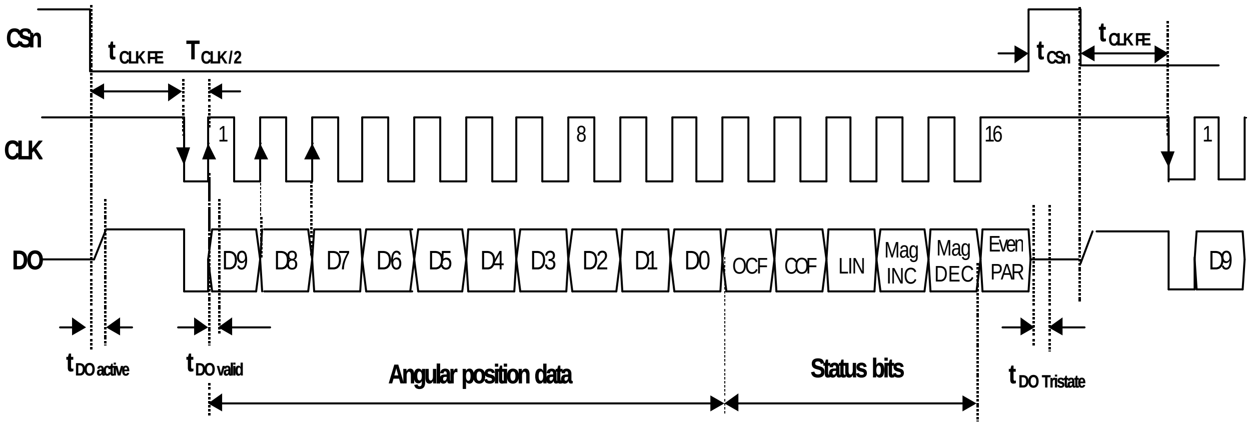

Figure 4 Synchronous serial interface with absolute angular position data

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, such as data valid, Parity and Magnetic Field status (increase/decrease) .
4. The next 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 (**O**ffset **C**ompensation **F**inished), logic high indicates the finished Offset Compensation Algorithm

COF (**C**ordic **O**ver**f**low), logic high indicates an out of range error in the CORDIC part. The absolute output maintains the last valid angular value.

LIN (**Lin**earity Alarm), logic high indicates that the input field generates a critical output linearity.

MagINC, (**Mag**nitude **Inc**rease) becomes HIGH, when the magnet is pushed towards the IC, thus the magnetic field strength is increasing.

MagDEC, (**Mag**nitude **Dec**rease) 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 2).

PAR Even Parity bit for transmission error detection

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 2 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 bits. Placing the magnet above the chip, angular values increase in clockwise direction by default.

If the CCW-bit is set to “1” at OTP register programming, the angular value will increase in counter clockwise direction.

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 (10 Hz) without skipping any position. By multiplying 10Hz by 60 sec / min, one obtains the corresponding maximum rotational speed of 600 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 4). 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 any 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.

10bit Pulse Width Modulation Output

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

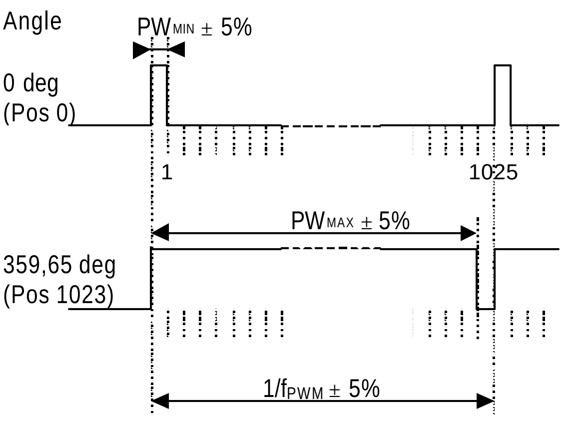

Figure 5 PWM output signal

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

Table 3 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=counter clockwise; top). 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 5).

High Speed Operation

High-speed encoders are mostly incremental and must not produce any 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 output for rotational speeds of up to 10,000 rpm

Absolute Output Mode Max. rotational speed [rpm]	Incremental Output Mode Max. rotational speed (Interpolated) [rpm]
4800 @ readout of 128 positions	10,000 rpm at any resolution
2400 @ readout of 256 positions	
1200 @ readout of 512 positions	
600 @ readout of 1024 positions	

Table 4 Speed performance

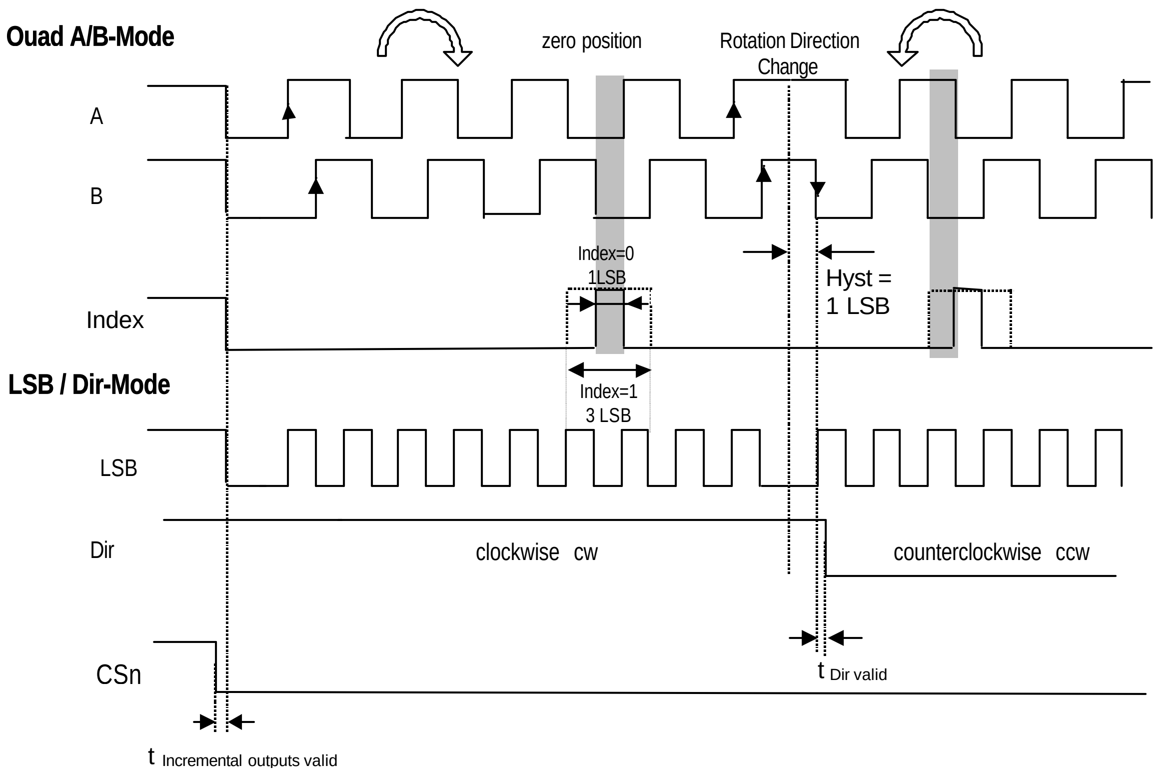

Figure 6 Incremental Output Modes

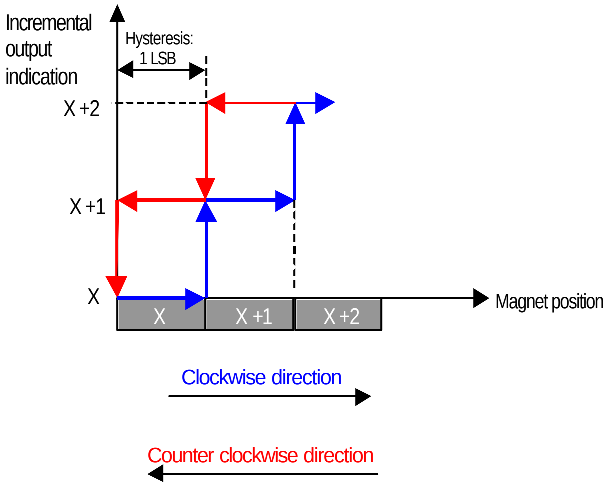

Figure 7..Hysteresis window for incremental outputs

Every incremental output shows a hysteresis of 1 LSB in case of any change of the rotational direction.

Regardless of the programmed incremental resolution, the hysteresis of 1 LSB always corresponds to the highest resolution of 10 bit. In absolute terms, the hysteresis is set to 0.352 degrees.

For constant rotational directions, every magnet position change is indicated at the incremental outputs. If for example the magnet turns clockwise and position „x+1“ is reached, the incremental output would also indicate this position accordingly.

A change of the magnet's rotational direction back to position „x“ means, that the incremental output still remains unchanged for the duration of 1 LSB. After this transition, the incremental outputs directly indicate every new position, if the rotational direction is constant.

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 5.

The U–commutation signal in mode 3.0 indicates with its falling edge position 512, which represents an absolute angular value of 180 degrees. Each position multiplied by 0.35 degrees (360 / 1024) equals the absolute angular value of that specific position. The same applies for every other signal and position. The pulse width of 512 positions is constant for each commutation signal (U-V-W) in mode 3.0.

Mode 3.2 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.

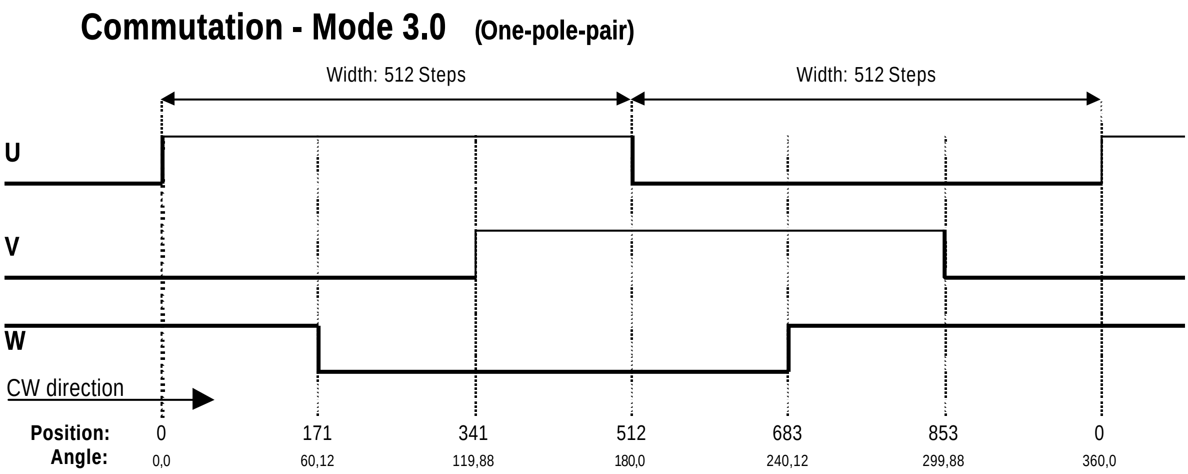

Figure 8 U, V and W-signals for BLDC motor commutation (DIV1 = 0; Div0 = 0)

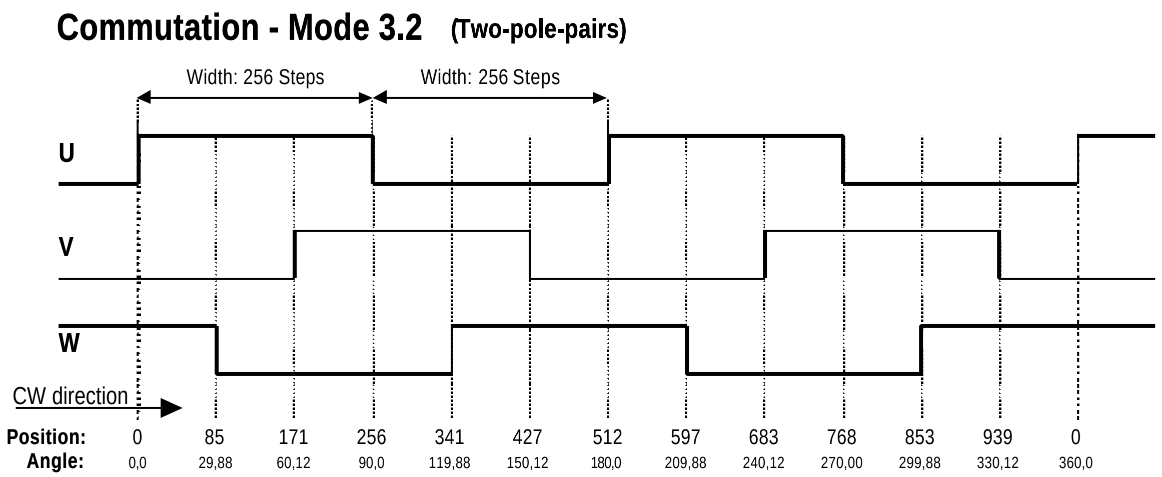

Figure 9 U, V and W-signals for 2 pole BLDC motor commutation (Div1=1; DIV0 = 0)

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).

After writing the data into the OTP register it can be permanently programmed ("zapped") by rising the Prog pin to the programming voltage V_{zapp}. 16 accurate CLK pulses (t_{zapp}) must be applied to program the fuses (Figure 10). The programmed data is available after the next power-on.

OTP Register Content:

CCW Counter Clockwise Bit

CCW=0 – angular value increases in clockwise direction

CCW=1 - angular value increases in counter clockwise direction

Z [9:0] Programmable Zero / Index Position

Indx Index Pulse Width Selection

Div1,Div0 Divider Setting of Incremental Output

Md1, Md0 Incremental Output Mode Selection

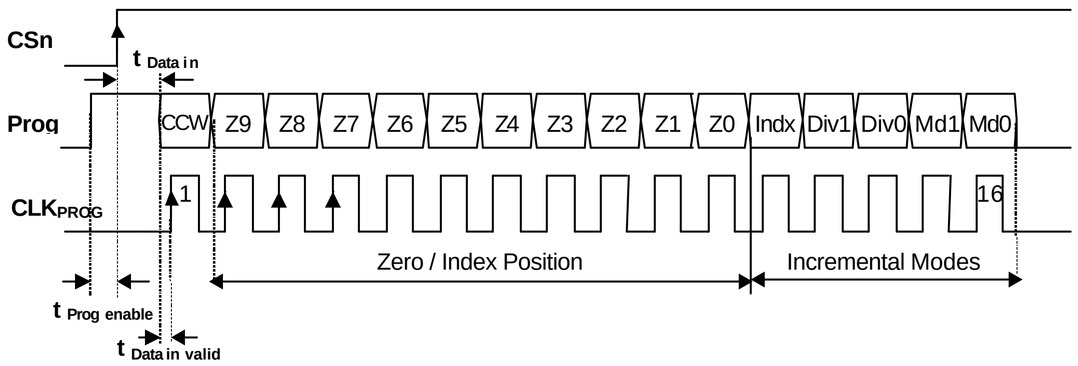

Figure 10 Programming Access – Write Data

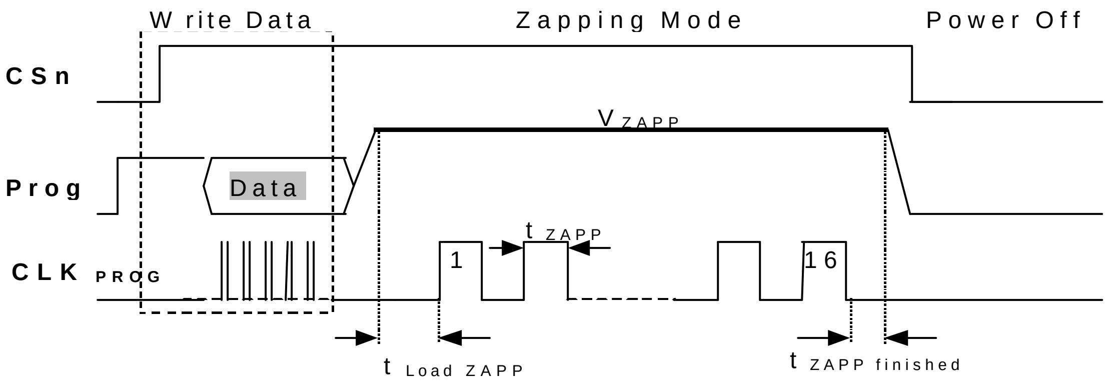

Figure 11 Programming Access – Zapp Data

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. The orientation (north/south pole) of the magnet does not need to be considered. The magnet only has to be set to the demanded zero position - that 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. Incremental Quadrature A/B with 1LSB Index pulse width is the default mode (see table 5). Programming the OTP-Register-bit Md1 replaces the quadrature A signal with the Least Significant Bit representation (LSB) and B with the rotation direction information (Dir) [LSB/Dir-Mode2.x].

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.

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 10) allows for changing this behaviour to accommodate the customer's requirements (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.

Especially for brush-less DC motor-control further programmable options (Commutation-Modes), are available. Md1 and Md0 set to logic high 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 or two-pole pair 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.

<table>
<tr><th></th><th colspan="5">OTP-Mode-Register-Bit</th><th colspan="4">PIN #</th><th>Pulses per Revolution</th><th>Incremental Resolution</th></tr>
<tr><th>Mode</th><th>Md1</th><th>Md0</th><th>Div1</th><th>Div0</th><th>Index</th><th>3</th><th>4</th><th>6</th><th>12</th><th>ppr</th><th>bit</th></tr>
<tr><td>Default (Mode0.0)</td><td>0</td><td>0</td><td>0*</td><td>0*</td><td>0*</td><td rowspan="9">A</td><td rowspan="9">B</td><td>1LSB</td><td rowspan="9">PWM 10bit</td><td rowspan="3">2x256</td><td rowspan="3">10</td></tr>
<tr><td>quadAB-Mode1.0</td><td>0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1LSB</td></tr>
<tr><td>quadAB-Mode1.1</td><td>0</td><td>1</td><td>0</td><td>0</td><td>1</td><td>3LSBs</td></tr>
<tr><td>quadAB-Mode1.2</td><td>0</td><td>1</td><td>0</td><td>1</td><td>0</td><td>1LSB</td><td rowspan="2">2x128</td><td rowspan="2">9</td></tr>
<tr><td>quadAB-Mode1.3</td><td>0</td><td>1</td><td>0</td><td>1</td><td>1</td><td>3LSBs</td></tr>
<tr><td>quadAB-Mode1.4</td><td>0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>1LSB</td><td rowspan="2">2x64</td><td rowspan="2">8</td></tr>
<tr><td>quadAB-Mode1.5</td><td>0</td><td>1</td><td>1</td><td>0</td><td>1</td><td>3LSBs</td></tr>
<tr><td>quadAB-Mode1.6</td><td>0</td><td>1</td><td>1</td><td>1</td><td>0</td><td>1LSB</td><td rowspan="2">2x32</td><td rowspan="2">7</td></tr>
<tr><td>quadAB-Mode1.7</td><td>0</td><td>1</td><td>1</td><td>1</td><td>1</td><td>3LSBs</td></tr>
<tr><td>LSB/Dir-Mode2.0</td><td>1</td><td>0</td><td>0</td><td>0</td><td>0</td><td rowspan="8">LSB</td><td rowspan="8">Dir</td><td>1LSB</td><td rowspan="8">PWM 10bit</td><td rowspan="2">512</td><td rowspan="2">10</td></tr>
<tr><td>LSB/Dir-Mode2.1</td><td>1</td><td>0</td><td>0</td><td>0</td><td>1</td><td>3LSBs</td></tr>
<tr><td>LSB/Dir -Mode2.2</td><td>1</td><td>0</td><td>0</td><td>1</td><td>0</td><td>1LSB</td><td rowspan="2">256</td><td rowspan="2">9</td></tr>
<tr><td>LSB/Dir -Mode2.3</td><td>1</td><td>0</td><td>0</td><td>1</td><td>1</td><td>3LSBs</td></tr>
<tr><td>LSB/Dir -Mode2.4</td><td>1</td><td>0</td><td>1</td><td>0</td><td>0</td><td>1LSB</td><td rowspan="2">128</td><td rowspan="2">8</td></tr>
<tr><td>LSB/Dir -Mode2.5</td><td>1</td><td>0</td><td>1</td><td>0</td><td>1</td><td>3LSBs</td></tr>
<tr><td>LSB/Dir -Mode2.6</td><td>1</td><td>0</td><td>1</td><td>1</td><td>0</td><td>1LSB</td><td rowspan="2">64</td><td rowspan="2">7</td></tr>
<tr><td>LSB/Dir -Mode2.7</td><td>1</td><td>0</td><td>1</td><td>1</td><td>1</td><td>3LSBs</td></tr>
<tr><td>Commutation-Mode3.0</td><td>1</td><td>1</td><td>0</td><td>0</td><td>0</td><td rowspan="2">U(0º)</td><td rowspan="2">V(120º)</td><td rowspan="2">W(240º)</td><td rowspan="2">LSB</td><td rowspan="2">3 x 1</td><td>10</td></tr>
<tr><td>Commutation-Mode3.1</td><td>1</td><td>1</td><td>0</td><td>1</td><td>0</td><td>9</td></tr>
<tr><td>Commutation-Mode3.2</td><td>1</td><td>1</td><td>1</td><td>0</td><td>0</td><td rowspan="2">U'
(0º, 180º)</td><td rowspan="2">V'
(60º,240º)</td><td rowspan="2">W'
(120º,300º)</td><td rowspan="2">LSB</td><td rowspan="2">2 x 3</td><td>10</td></tr>
<tr><td>Commutation-Mode3.3</td><td>1</td><td>1</td><td>1</td><td>1</td><td>0</td><td>9</td></tr>
</table>

Table 5 One Time Programmable (OTP) register options

.Note: LSB, A, B do have programmable resolution

Alignment Mode

The magnet alignment is supported with an alignment procedure helping to find the optimum magnet position. After power-on the sensor configuration for aligning the magnet can be enabled with the falling edge of CSn and Prog = logic high. The Data bits D9-D0 of the SSI change to a 10bit displacement amplitude output and must be minimised by shifting the two pole magnet in X and Y direction. The device can only be reset to the normal operation mode by a power-on-reset. MagINCn and MagDECn are indicating additionally a non-valid range signal (MagINCn = MagDECn = 0 = valid range).

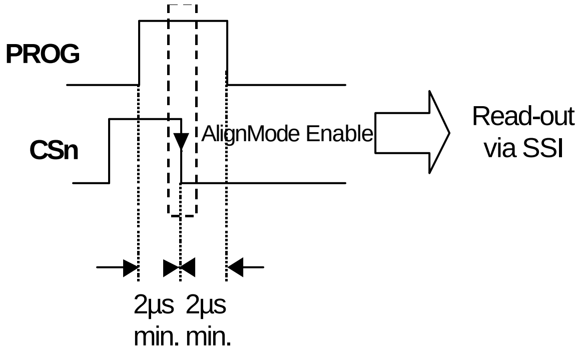

Figure 12 Enabling the alignment mode

3.3V / 5V Operation

The AS5040 operates either at 3.3V ±10% or at 5V ±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 13).

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 13).

The HIGH output voltages of the various output ports correspond to the applied supply voltage, thus it is either 5V or 3.3V

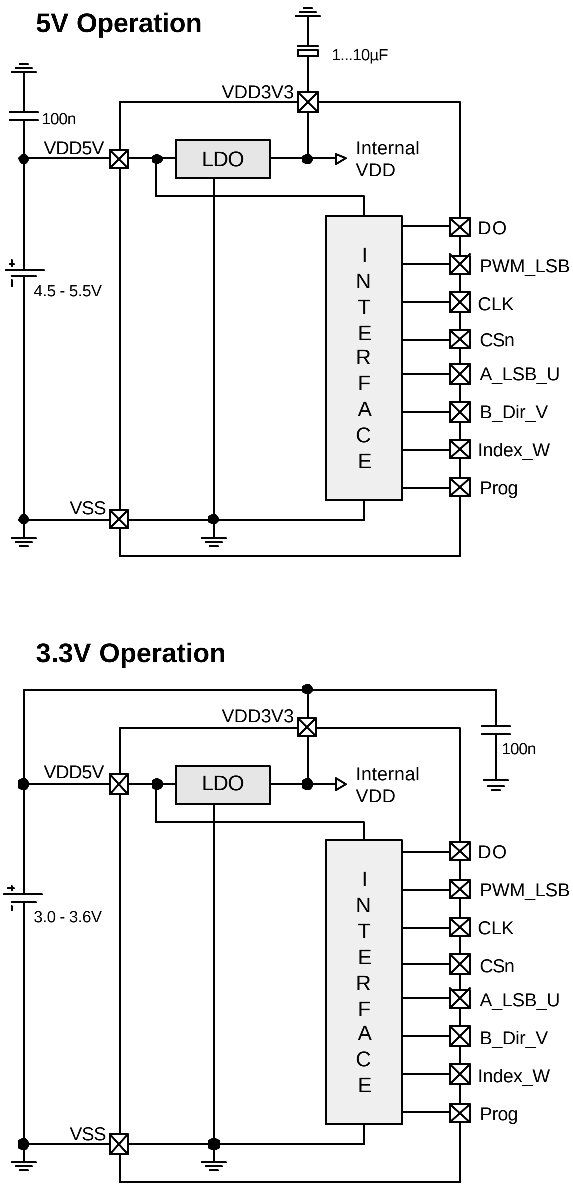

Figure 13 Connections for 5V / 3.3V supply voltages

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

Magnetic Source

Typically the magnet dimensions 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 ±45…±75mT (peak).

In order to make sure those requirements are met, the magnet's field strength has to be measured along a concentric circle with a radius of 1.1mm (R1), referenced to the magnetic center (axis) of the diametrically magnetised magnet.

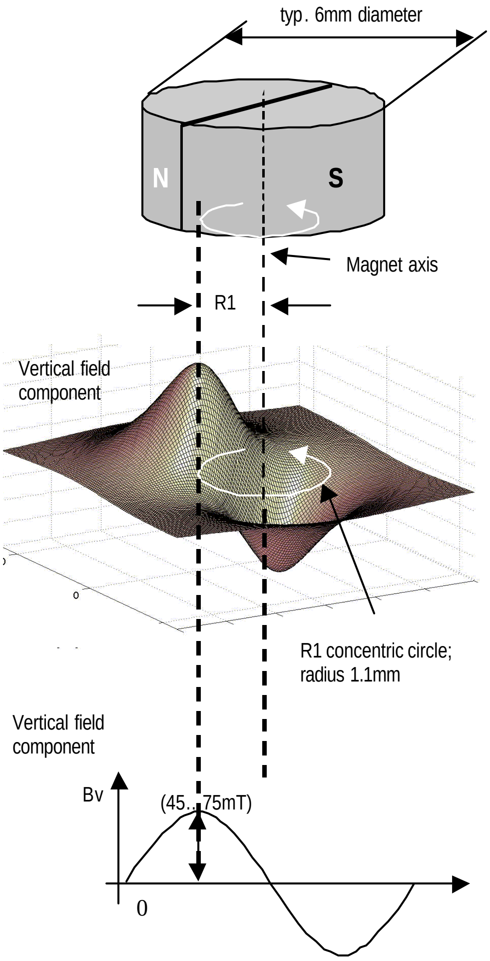

Figure 13 Typical magnet (6x3mm) and magnetic field distribution

Physical Placement of the Magnet

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

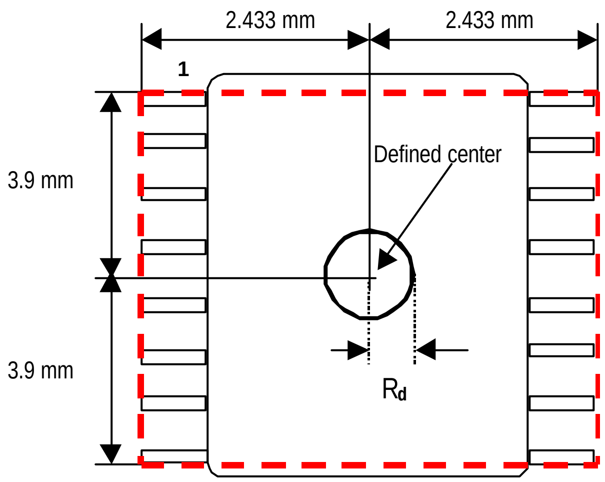

Figure 15 Defined center and displacement radius Rd

Magnet placement:

The magnet's axis should be aligned within a radius Rd of 0.25mm (displacement radius Rd) with respect to the defined center.

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 of ±45…±75mT (see figure13). 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 would be indicated by MagINCn (pin 1) and MagDECn (pin 2).

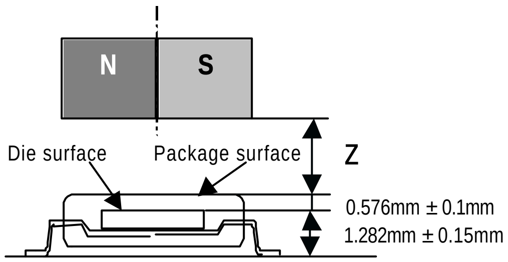

Figure 16 Vertical placement of the magnet

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_{in}	-0.3	VDD+0.3	V	
Input current (latchup immunity)	I_{scr}	-100	100	mA	Norm: Jedec 17
Electrostatic discharge	ESD	±1		kV	Norm: MIL 883 E method 3015
Storage temperature	T_{strg}	-55	125	°C	Min – 67°F ; Max +257°F
Body temperature (Lead-free package)	T_{Body}		250	°C	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	Tamb	-40		125	°C	-40°F…+257°F
Supply current	Isupp		16	20	mA	
Supply voltage at pin VDD5V Voltage regulator output voltage at pin VDD3V3	VDD5V VDD3V3	4.5 3.0	5.0 3.3	5.5 3.6	V V	5V Operation
Supply voltage at pin VDD5V Supply voltage at pin VDD3V3	VDD5V VDD3V3	3.0 3.0	3.3 3.3	3.6 3.6	V V	3.3V Operation (pin VDD5V and VDD3V3 connected)

DC Characteristics for Digital Inputs and Output

CMOS Input: CLK, CSn=Pull-up; Schmitt Trigger Inputs

Parameter	Symbol	Min	Max	Unit	Note
High level input voltage	V_{IH}	0.7 * VDD5V		V	
Low level input voltage	V_{IL}		0.3 * VDD5V	V	
Input leakage current	I_{LEAK}	-1	1	µA	CLK only
Pullup low level input current	I_{iL}	-30	-100	µA	CSn only, VDD5V: 5.0V
Negative-going threshold	V_{t-}	1,62	1.78	V	VDD5V = 4.5V
		2,04	2.22		VDD5V = 5.5V
Positive-going threshold	V_{t+}	2.72	2.89	V	VDD5V = 4.5V
		3.34	3.42		VDD5V = 5.5V

CMOS / Program Input: Prog

Parameter	Symbol	Min	Max	Unit	Note
High level input voltage	V_{IH}	0.7 * VDD5V	5	V	
Low level input voltage	V_{IL}		0.3 * VDD5V	V	
Pulldown high level input current	I_{iL}		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	µA	

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	µA	

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}		±10	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: max rotational speed of 600 rpm @ 10 bit readout
	f_{mag_inc}		166	Hz	Incremental mode: max 10,000 rpm @ 7, 8, 9 or 10 bit resolution
Magnetic field temperature drift	B_{tc}			%/K	Samarium Cobalt ReComa28 typ. – 0.035 %/K
Displacement radius	Disp		0.25	mm	Max. offset between defined device center and magnet axis (see figure 15)

Electrical System Specifications

Parameter	Symbol	Min	Typ	Max	Unit	Note
Resolution	RES			10	bit	0.352 deg
7 bit 8 bit 9 bit 10 bit			2.813 1.406 0.703 0.352		deg	Adjustable resolution only available for incremental output modes; Least significant bit, minimum step

Parameter	Symbol	Min	Typ	Max	Unit	Note
Integral non-linearity (optimum)	INL_{opt}			±0.5	deg	Maximum error with respect to the best line fit. Verified at optimum placement @ 25 °C.
Integral non-linearity	INL			±1.4	deg	Best line fit over displacement tolerance and full operating temperature range
Differential non-linearity	DNL			±0.176	deg	10bit no missing codes
Transition noise	TN			±0.176	deg	± 3 sigma; (±0.176 degrees equivalent to ±0.5LSB)
Hysteresis	Hyst			1	LSB	See page 7
Power-on reset thresholds						
On Voltage; 300mV typ. Hysteresis	V_{on}	1,37	2.2	2.9	V	DC supply voltage 3.3V (VDD3V3)
Off Voltage; 300mV typ. Hysteresis	V_{off}	1.08	1.9	2.6	V	DC supply voltage 3.3V (VDD3V3)
Power-up time	t_{PwrUp}	100		820 *	ms	*…Until offset compensation finished
System propagation delay absolute output	t_{delay}			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_S	9.5	10	10.5	kHz	Internal sampling rate
Read-out frequency	CLK			1	MHz	Max. clock frequency to read out serial data

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	$t_{DO\ valid}$			5	ns	Time between first 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	CLK			1	MHz	Max. 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 µs
Minimum pulse width	PW_{MIN}	0.95	1	1.05	µs	Position 0d; Angle 0 degree
Maximum pulse width	PW_{MAX}	973	1024	1075	µs	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			µs	Time between rising edge at Prog pin and rising edge of CSn

Parameter	Symbol	Min	Typ	Max	Unit	Note
Write data start	$t_{Data\ in}$	2			µs	
Write data valid	$t_{Data\ in\ valid}$	250			ns	Write data at the rising edge of CLK_{PROG}
Load ZAPP data	$t_{Load\ ZAPP}$		2		µs	
Write data – programming CLK_{PROG}	CLK_{PROG}		250		kHz	
ZAPP data – CLK pulse width	t_{ZAPP}	1.8	2	2.2	µs	
ZAPP finished	$t_{ZAPP\ finished}$	2			µs	Programmed data is available after next power-on
Programming voltage	V_{PROG}	7.3	7.4	7.5	V	Must be switched off after zapping
Programming current	I_{PROG}			130	mA	

MARKING

Package type: SSOP16 (5.3mm x 6.2mm) [Leadfree]

Marking: AYWWIZZ

A ... Pb-free identifier

Y ... year

WW ... week

I ... plant identifier

ZZ ... letters of free choice

Last Line: AS5040

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

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