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AS5040

10Bit 360º Programmable Magnetic Rotary Encoder

General Description

The AS5040 is a contactless magnetic rotary encoder for accurate angular measurement over a full turn of 360°. It is a system-on-chip, combining integrated Hall elements, analog front end and digital signal processing in a single device.

To measure the angle, only a simple two-pole magnet, rotating over the center of the chip, is required. The magnet may be placed above or below the IC.

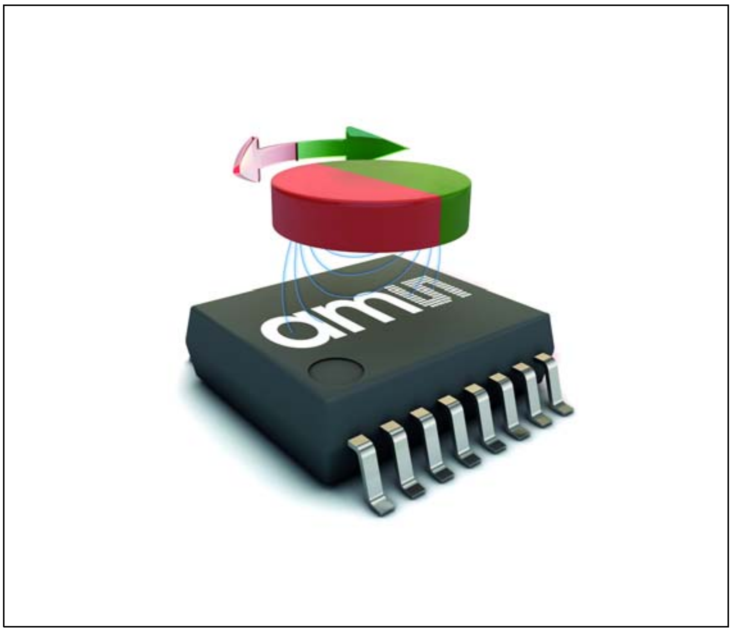
The absolute angle measurement provides instant indication of the magnet's angular position with a resolution of 0.35° = 1024 positions per revolution. This digital data is available as a serial bit stream and as a PWM signal.

Furthermore, a user-programmable incremental output is available, making the chip suitable for replacement of various optical encoders.

An internal voltage regulator allows the AS5040 to operate at either 3.3 V or 5 V supplies.

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

Figure 1:
Typical Arrangement of AS5040 and Magnet



Key Benefits & Features

The benefits and features of AS5040, 10Bit 360º Programmable Magnetic Rotary Encoder are listed below:

Figure 2:
Added Value of Using AS5040

Benefits	Features
• Highest reliability and durability	• Contactless high resolution rotational position encoding over a full turn of 360 degrees
• Simple programming	• Simple user-programmable resolution, pole pairs and zero position
• Multiple interfaces	• Serial communication interface (SSI) • 10-bit pulse width modulated (PWM) output • Quadrature A/B and Index output signal • Step/Direction and Index output signal • 3-Phase commutation for brushless DC motors
• Ideal for motor applications	• Rational speeds up to 30,000 rpm
• Failure diagnostics	• Failure detection mode for magnet placement monitoring and loss of power supply
• Easy setup	• Serial read-out of multiple interconnected devices using daisy chain mode
• Great flexibility at a huge application area	• Push button functionality detects movement of magnet in Z-axis
• Fully automotive qualified	• AEC-Q100, grade 1
• Small form factor	• SSOP 16 (5.3mm x 6.2mm)
• Robust environmental tolerance	• Wide temperature range: -40°C to 125°C

Applications

AS5040 is ideal for:

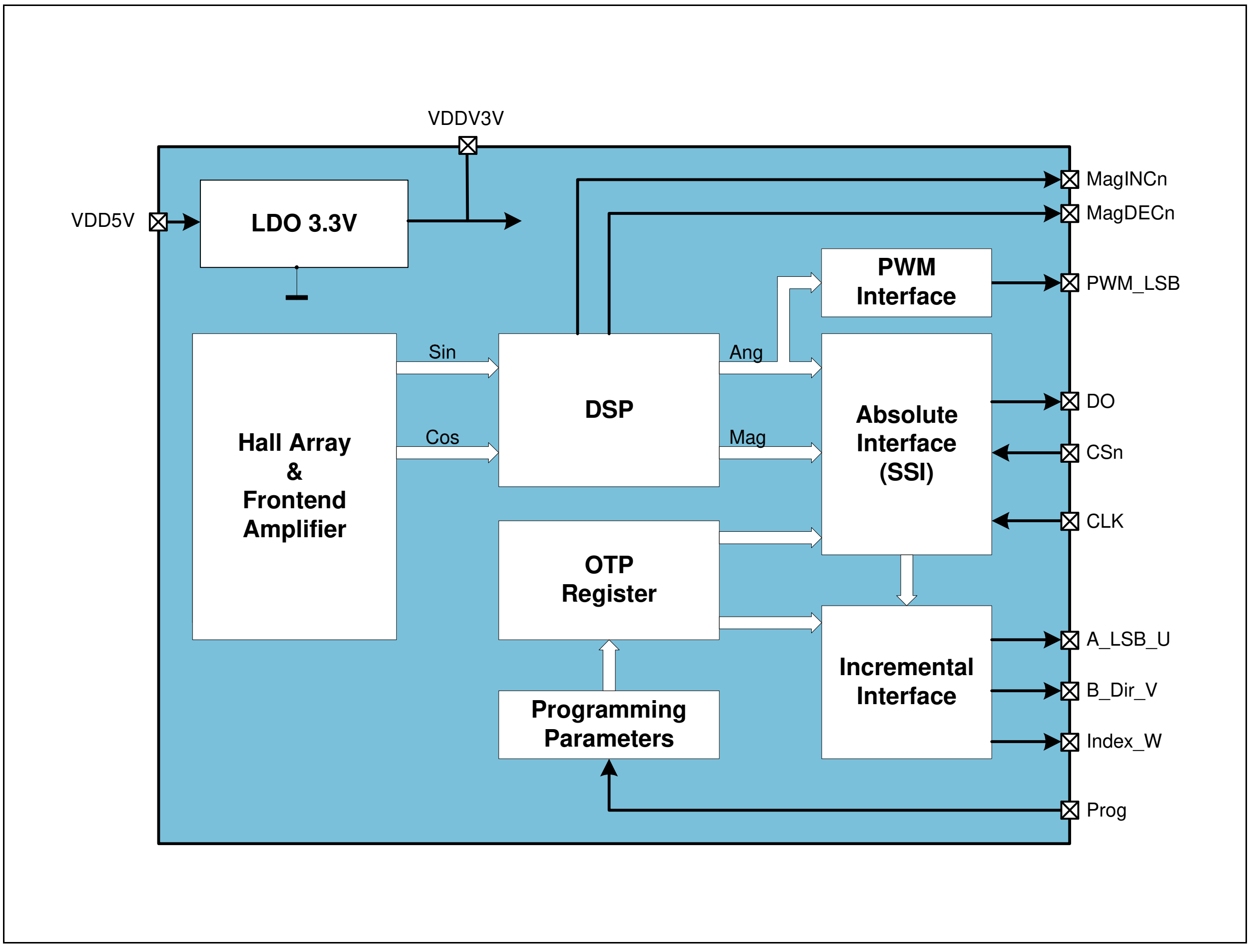
- Industrial applications:
  - Contactless rotary position sensing
  - Robotics
  - Brushless DC motor commutation
  - Power tools
- Automotive applications:
  - Steering wheel position sensing
  - Gas pedal position sensing
  - Transmission gearbox encoder
  - Headlight position control
  - Power seat position indicator

- Office equipment: printers, scanners, copiers
- Replacement of optical encoders
- Front panel rotary switches
- Replacement of potentiometers

Block Diagram

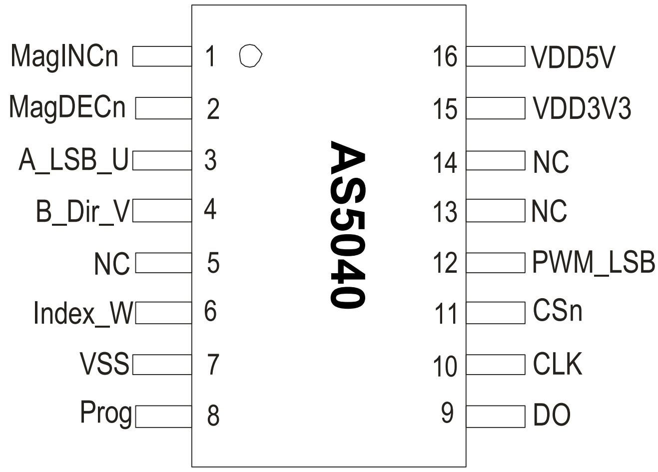
The functional blocks of this device are shown below:

Figure 3:
AS5040 Block Diagram



Pin Assignment

Figure 4:
Pin Configuration SSOP16



Pin Description

Figure 6 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 4).

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.

Figure 5:
Pin Assignment for the Different Incremental Output Modes

Output Mode	Pin 3	Pin 4	Pin 6	Pin 12
1.x: quadrature	A	B	Index	PWM
2.x:step/direction	LSB	Direction	Index	PWM
3.x: commutation	U	V	W	LSB

Mode 1.x: Quadrature A/B Output

Represents the default quadrature A/B signal mode.

Mode 2.x: Step / Direction Output

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

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

Mode 3.x: Brushless DC Motor Commutation Mode

In addition to the absolute encoder output over the SSI interface, this mode provides commutation signals for brushless DC motors with either one pole pair or two pole pair rotors. The commutation signals are usually provided by 3 discrete Hall switches, which are no longer required, as the AS5040 can fulfill two tasks in parallel: absolute encoder + BLDC motor commutation.

In this mode, pin 12 provides the LSB output instead of the PWM (Pulse-Width-Modulation) signal.

Pin 8 (Prog) is also used to program the different incremental interface modes, the incremental resolution and the zero position into the OTP.

This pin is also used as digital input to shift serial data through the device in Daisy Chain configuration.

Pin 11 Chip Select (CSn; active low) selects a device within a network of AS5040 encoders and initiates serial data transfer. A logic high at CSn puts the data output pin (DO) to tri-state and terminates serial data transfer. This pin is also used for Alignment Mode and Programming the AS5040.

Pin 12 allows a single wire output of the 10-bit absolute position value. The value is encoded into a pulse width modulated signal with 1µs pulse width per step (1µs to 1024µs over a full turn). By using an external low pass filter, the digital PWM signal is converted into an analog voltage, allowing a direct replacement of potentiometers.

Figure 6:
Pin Description SSOP16

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.

Pin	Symbol	Type	Description
3	A_LSB_U	DO	*Mode1.x:* Quadrature **A** channel *Mode2.x:* **L**east **S**ignificant **B**it *Mode3.x:* **U** signal (phase1)
4	B_Dir_V	DO	*Mode1.x*: Quadrature **B** channel quarter period shift to channel A. *Mode2.x:* **Dir**ection of Rotation *Mode3.x:* **V** signal (phase2)
5	NC	-	Must be left unconnected
6	Index_W	DO	*Mode1.x and Mode2.x*: **Index** signal indicates the absolute zero position *Mode3.x*: **W** signal (phase3)
7	VSS	S	Negative Supply Voltage (GND)
8	Prog	DI_PD	OTP **Prog**ramming Input and Data Input for Daisy Chain mode. Internal pull-down resistor (~74kΩ). May be connected to VSS if programming is not used
9	DO	DO_T	**D**ata **O**utput of Synchronous Serial Interface
10	CLK	DI, ST	**Cl**oc**k** Input of Synchronous Serial Interface; Schmitt-Trigger input
11	CSn	DI_PU, ST	**C**hip **S**elect, active low; Schmitt-Trigger input, internal pull-up resistor (~50kΩ) connect to VSS in incremental mode (see 0)
12	PWM_LSB	DO	**P**ulse **W**idth **M**odulation of approx. 1kHz; **LSB** in *Mode3.x*
13	NC	-	Must be left unconnected
14	NC	-	Must be left unconnected
15	VDD3V3	S	3V-Regulator Output (see Figure 39)
16	VDD5V	S	Positive Supply Voltage 5 V

Abbreviations for Pin Types in Figure 6:

DO_OD : Digital output open drain

DO : Digital output

DI_PD : Digital input pull-down

DI_PU : Digital input pull-up

S : Supply pin

DI : Digital input

DO_T : Digital output /tri-state

ST : Schmitt-Trigger input

Absolute Maximum Ratings

Stresses beyond those listed in 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 in 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	Units	Note
VDD5V	DC supply voltage at pin VDD5V	-0.3	7	V	
VDD3V3	DC supply voltage at pin VDD3V3	-0.3	5	V	
Vin	Input pin voltage	-0.3	VDD5V +0.3	V	Pins MagINCn, MagDECn, CLK, CSn
		-0.3	7.5		Pin Prog
I_{scr}	Input current (latchup immunity)	-100	100	mA	Norm: JEDEC 78
ESD	Electrostatic discharge	±2		kV	Norm: MIL 883 E method 3015
T_{strg}	Storage temperature	-55	125	ºC	Min – 67°F, Max 257°F
T_{Body}	Body temperature (Lead free package)		260	ºC	t=20 to 40s, Norm: IPC/JEDEC J-Std-020C Lead finish 100% Sn “matte tin”
RH_{NC}	Relative humidity (non condensing)	5	85	%	
MSL	Moisture sensitivity level	3			Maximum floor life time of 168h

Electrical Characteristics

Operating Conditions

Figure 8:
Operating Conditions

Symbol	Parameter	Min	Typ	Max	Unit	Note
T_{amb}	Ambient temperature	-40		125	°C	-40°F to 257°F
I_{supp}	Supply current		16	21	mA	
VDD5V VDD3V3	External supply voltage at pin VDD5V Internal regulator output voltage at pin VDD3V3	4.5 3.0	5.0 3.3	5.5 3.6	V V	5V operation
VDD5V VDD3V3	External supply voltage at pin VDD5V, VDD3V3	3.0 3.0	3.3 3.3	3.6 3.6	V V	3.3V operation (pins VDD5V and VDD3V3 connected)

DC Characteristics for Digital Inputs and Outputs

CMOS Schmitt-Trigger Inputs: CLK, CSn (CSn = Internal Pull-Up)

Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Figure 9:
CMOS Schmitt-Trigger Inputs: CLK, CSn (CSn = Internal Pull-Up)

Symbol	Parameter	Min	Max	Unit	Note
V_{IH}	High level input voltage	0.7 * VDD5V		V	Normal operation
V_{IL}	Low level input voltage		0.3 * VDD5V	V	
V_{Ion}-V_{Ioff}	Schmitt trigger hysteresis	1		V	
I_{LEAK}	Input leakage current	-1	1	µA	CLK only
I_{iL}	Pull-up low level input current	-30	-100	µA	CSn only, VDD5V: 5.0V

CMOS / Program Input: Prog

Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Figure 10:
CMOS / Program Input: Prog

Symbol	Parameter	Min	Max	Unit	Note
V_{IH}	High level input voltage	0.7 * VDD5V	5	V	
V_{PROG}	High level input voltage	See Programming Conditions		V	During programming
V_{IL}	Low level input voltage		0.3 * VDD5V	V	
I_{iL}	Pull-down high level input current		100	µA	VDD5V: 5.5V

CMOS Output Open Drain: MagINCn, MagDECn

Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Figure 11:
CMOS Output Open Drain: MagINCn, MagDECn

Symbol	Parameter	Min	Max	Unit	Note
V_{OL}	Low level output voltage		VSS+0.4	V	
I_O	Output current		4 2	mA	VDD5V: 4.5V VDD5V: 3V
I_{OZ}	Open drain leakage current		1	µA	

CMOS Output: A, B, Index, PWM

Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Figure 12:
CMOS Output: A, B, Index, PWM

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

Tristate CMOS Output: DO

Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Figure 13:
Tristate CMOS Output: DO

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

Magnetic Input Specification

Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Two-pole cylindrical diametrically magnetized source:

Figure 14:
Magnetic Input Specification

Symbol	Parameter	Min	Typ	Max	Unit	Note
d_{mag}	Diameter	4	6		mm	Recommended magnet: Ø 6mm x 2.5mm for cylindrical magnets
t_{mag}	Thickness	2.5			mm	
B_{pk}	Magnetic input field amplitude	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
B_{off}	Magnetic offset			± 10	mT	Constant magnetic stray field
	Field non-linearity			5	%	Including offset gradient
f_{mag_abs}	Input frequency (rotational speed of magnet)			10	Hz	Absolute mode: 600 rpm @ readout of 1024 positions (see Figure 36)
f_{mag_inc}				500	Hz	Incremental mode: no missing pulses at rotational speeds of up to 30,000 rpm (see Figure 36)
Disp	Displacement radius			0.25	mm	Max. X-Y offset between defined IC package center and magnet axis (see Figure 41)
				0.485		Max. X-Y offset between chip center and magnet axis.
	Chip placement tolerance			±0.235	mm	Placement tolerance of chip within IC package (see Figure 43)
	Recommended magnet material and temperature drift		-0.12		%/K	NdFeB (Neodymium Iron Boron)
			-0.035			SmCo (Samarium Cobalt)

Electrical System Specifications

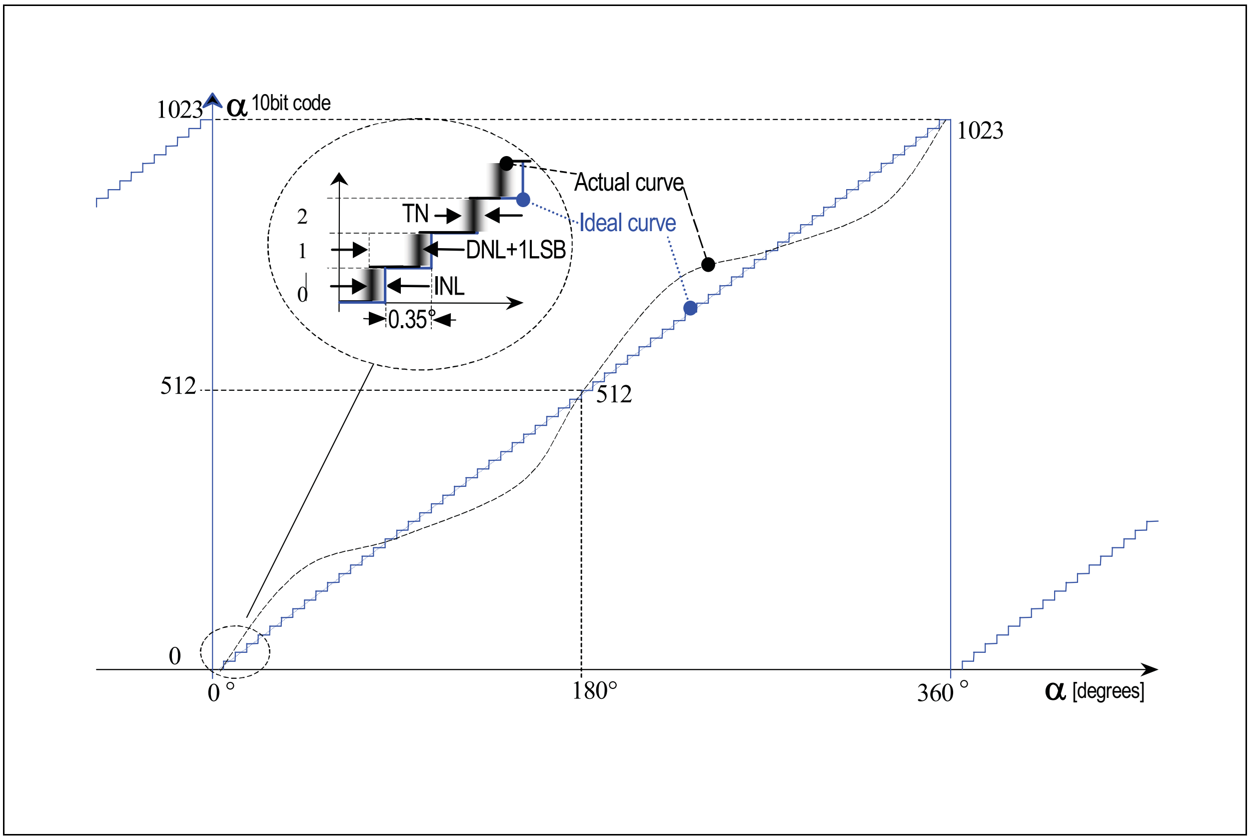
Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Figure 15:
Electrical System Specifications

Symbol	Parameter	Min	Typ	Max	Unit	Note
RES	Resolution			10	bit	0.352 deg
LSB	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
INL_{opt}	Integral non-linearity (optimum)			± 0.5	deg	Maximum error with respect to the best line fit. Verified at optimum magnet placement, T_{amb} =25 °C.
INL_{temp}	Integral non-linearity (optimum)			± 0.9	deg	Maximum error with respect to the best line fit. Verified at optimum magnet placement, T_{amb} = -40°C to 125°C
INL	Integral non-linearity			± 1.4	deg	Best line fit = (Err_{max} – Err_{min}) / 2 Over displacement tolerance with 6mm diameter magnet, T_{amb} = -40°C to 125°C
DNL	Differential non-linearity			±0.176	deg	10bit, no missing codes
TN	Transition noise			0.12	Deg RMS	RMS equivalent to 1 sigma
Hyst	Hysteresis		0.704		deg	Incremental modes only
V_{on}	Power-on-reset threshold ON voltage; 300mV typ. hysteresis	1.37	2.2	2.9	V	DC supply voltage 3.3V (VDD3V3)
V_{off}	Power-on-reset threshold OFF voltage; 300mV typ. hysteresis	1.08	1.9	2.6	V	DC supply voltage 3.3V (VDD3V3)
t_{PwrUp}	Power-up time			50	ms	Until offset compensation finished
t_{delay}	System propagation delay absolute output			48	µs	Includes delay of ADC and DSP
	System propagation delay incremental output			192	µs	Calculation over two samples

Symbol	Parameter	Min	Typ	Max	Unit	Note
f_S	Sampling rate for absolute output	9.90	10.42	10.94	kHz	Internal sampling rate, T_{amb} = 25°C
		9.38	10.42	11.46		Internal sampling rate, T_{amb} = -40°C to 125°C
CLK	Read-out frequency			1	MHz	Max. clock frequency to read out serial data

Figure 16:
Integral and Differential Non-Linearity Example (Exaggerated Curve)



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)

Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Figure 17:
Synchronous Serial Interface (SSI)

Symbol	Parameter	Min	Typ	Max	Unit	Note
$t_{DO\ active}$	Data output activated (logic high)			100	ns	Time between falling edge of CSn and data output activated
$t_{CLK\ FE}$	First data shifted to output register	500			ns	Time between falling edge of CSn and first falling edge of CLK
$T_{CLK\ /\ 2}$	Start of data output	500			ns	Rising edge of CLK shifts out one bit at a time
$t_{DO\ valid}$	Data output valid	357		413	ns	Time between rising edge of CLK and data output valid
$t_{DO\ tristate}$	Data output tristate			100	ns	After the last bit DO changes back to "tristate"
t_{CSn}	Pulse width of CSn	500			ns	CSn = high; To initiate read-out of next angular position
f_{CLK}	Read-out frequency	>0		1	MHz	Clock frequency to read out serial data

Pulse Width Modulation Output

Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Figure 18:
Pulse Width Modulation Output

Symbol	Parameter	Min	Typ	Max	Unit	Note
f_{PWM}	PWM frequency	0.927	0.976	1.024	KHz	Signal period = 1025µs ±5% at T_{amb} = 25°C
		0.878	0.976	1.074		=1025µs ±10% at T_{amb} = -40°C to 125°C
PW_{MIN}	Minimum pulse width	0.90	1	1.10	µs	Position 0d; angle 0 degree
PW_{MAX}	Maximum pulse width	922	1024	1126	µs	Position 1023d; angle 359.65 degree

Incremental Outputs

Operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted.

Figure 19:
Incremental Outputs

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

Programming Conditions

(operating conditions: T_{amb} = -40°C to 125°C, VDD5V = 3.0V to 3.6V (3V operation) VDD5V = 4.5V to 5.5V (5V operation) unless otherwise noted).

Figure 20:
Programming Conditions

Symbol	Parameter	Min	Typ	Max	Unit	Note
$t_{Prog\ enable}$	Programming enable time	2			µs	Time between rising edge at Prog pin and rising edge of CSn
$t_{Data\ in}$	Write data start	2			µs	
$t_{Data\ in\ valid}$	Write data valid	250			ns	Write data at the rising edge of CLK_{PROG}
$t_{Load\ PROG}$	Load programming data	3			µs	
t_{PrgR}	Rise time of V_{PROG} before CLK_{PROG}	0			µs	
t_{PrgH}	Hold time of V_{PROG} after CLK_{PROG}	0		5	µs	
CLK_{PROG}	Write data – programming CLK_{PROG}			250	kHz	
t_{PROG}	CLK pulse width	1.8	2	2.2	µs	During programming; 16 clock cycles
$t_{PROG\ finished}$	Hold time of Vprog after programming	2			µs	Programmed data is available after next power-on
V_{PROG}	Programming voltage	7.3	7.4	7.5	V	Must be switched OFF after zapping
$V_{ProgOff}$	Programming voltage OFF level	0		1	V	Line must be discharged to this level
I_{PROG}	Programming current			130	mA	During programming
CLK_{Aread}	Analog read CLK			100	kHz	Analog readback mode
$V_{programmed}$	Programmed zener voltage (log.1)			100	mV	V_{Ref}-V_{PROG} during analog readback mode (see Analog Readback Mode)
$V_{unprogrammed}$	Unprogrammed zener voltage (log. 0)	1			V	

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 40).

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).

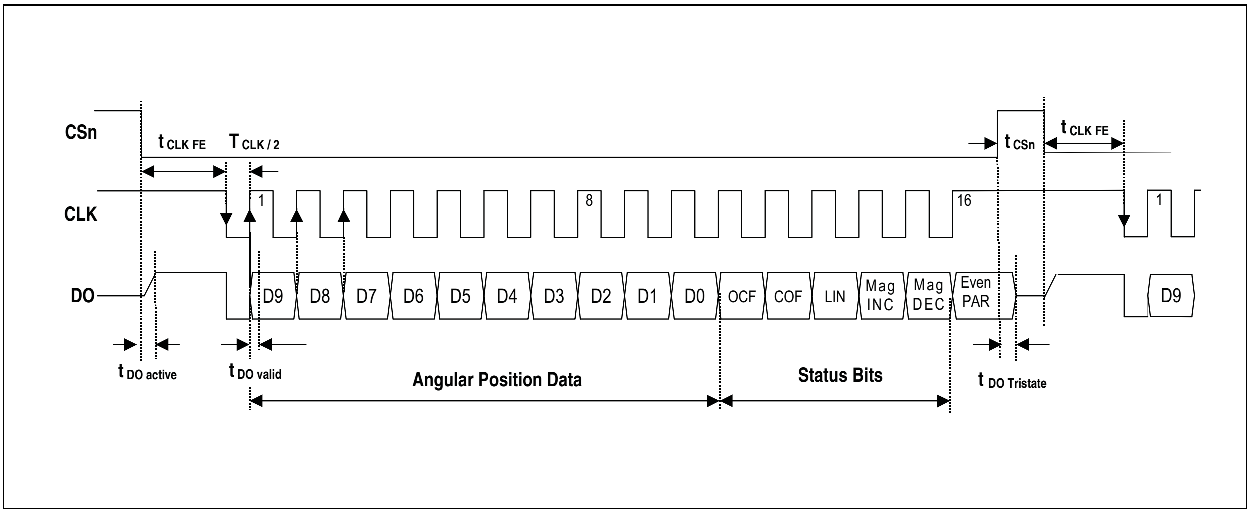
Besides the absolute angular position information the device simultaneously provides incremental output signals. The various incremental output modes can be selected by programming the OTP mode register bits (see Figure 36). As long as no programming voltage is applied to pin Prog, the new setting may 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 programmed (see Figure 34). The default setting is a quadrature A/B mode including the Index signal with a pulse width of 1 LSB. The Index signal is logic high at the user programmable zero position.

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

10-Bit Absolute Angular Position Output

Synchronous Serial Interface (SSI)

Figure 21:
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.

- After a minimum time $t_{CLK\ FE}$, data is latched into the output shift register with the first falling edge of CLK.
- Each subsequent rising CLK edge shifts out one bit of data.
- 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).
- A subsequent measurement is initiated by a log. “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. For fast startup, this bit may be polled by the external microcontroller. As soon as this bit is set, the AS5040 has completed the startup and the data is valid (see Figure 23)

COF (**C**ORDIC **O**verflow), 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 (**Lin**earity Alarm), logic high indicates that the input field generates a critical output linearity. When this 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.

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

MagDECn, (**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 Figure 22).

Figure 22:
Magnetic Magnitude Variation Indicator

Mag INCn	Mag DECn	Description
0	0	No distance change; Magnetic input field OK (in range, 45mT to 75mT)
0	1	Distance increase: Pull-function. This state is dynamic, it is only active while the magnet is moving away from the chip in Z-axis
1	0	Distance decrease: Push- function. This state is dynamic, it is only active while the magnet is moving towards the chip in Z.-axis.
1	1	Magnetic Input Field invalid – out of range: <45mT or >75mT (or missing magnet)

Note(s) and/or Footnote(s):

1. Pins 1 and 2 (MagINCn, MagDECn) are open drain outputs and require external pull-up resistors. If the magnetic field is in range, both outputs are turned OFF.

The two pins may also be combined with a single pull-up resistor. In this case, the signal is high when the magnetic field is in range. It is low in all other cases (see Figure 22).

Even Parity bit for transmission error detection of bits 1 to 15 (D9 to D0, OCF, COF, LIN, MagINCn, MagDECn).

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 D9:D0 is valid, when the status bits have the following configurations:

Figure 23:
Status Bit Outputs

OCF	COF	LIN	Mag INCn	Mag DECn	Parity
1	0	0	0	0	Even checksum of bits 1:15
			0	1	
			1	0	

The absolute angular position is sampled at a rate of 10kHz (0.1ms). This allows reading of all 1024 positions per 360 degrees within 0.1 seconds = 9.76Hz (~10Hz) without skipping any position. Multiplying 10Hz by 60, results the corresponding maximum rotational speed of 600 rpm.

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

Consequently, increasing the rotational speed reduces the number of absolute angular positions per revolution (see Figure 46). 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 30,000 rpm without missing pulses.

Daisy Chain Mode

The Daisy Chain mode allows connection of several AS5040's in series, while still keeping just one digital input for data transfer (see "Data IN" in Figure 24 below). This mode is accomplished by connecting the data output (DO; pin 9) to the data input (Prog; pin 8) of the subsequent device. An RC filter must be implemented between each PROG pin of device n and DO pin of device n+1, to prevent the encoders to enter the alignment mode, in case of ESD discharge, long cables, or not conform signal levels or shape. Using the values R=100R and C=1nF allow a max. CLK frequency of 1MHz on the whole chain. The serial data of all connected devices is read from the DO pin of the first device in the chain. The Prog pin of the last device in the chain should be connected to VSS. The length of the serial bit stream increases with every connected device, it is

n * (16+1) bits:

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

The last data bit of the first device (Parity) is followed by a logic low bit and the first data bit of the second device (D9), etc… (see Figure 25).

Programming Daisy Chained Devices

In Daisy Chain mode, the Prog pin is connected directly to the DO pin of the subsequent device in the chain (see Figure 24). During programming (see Programming the AS5040), a programming voltage of 7.5V must be applied to pin Prog. This voltage level exceeds the limits for pin DO, so one of the following precautions must be made during programming:

- Open the connection DO -> Prog during programming or
- Add a Schottky diode between DO and Prog (Anode = DO, Cathode = Prog)

Due to the parallel connection of CLK and CSn, all connected devices may be programmed simultaneously.

Figure 24:
Daisy Chain Hardware Configuration

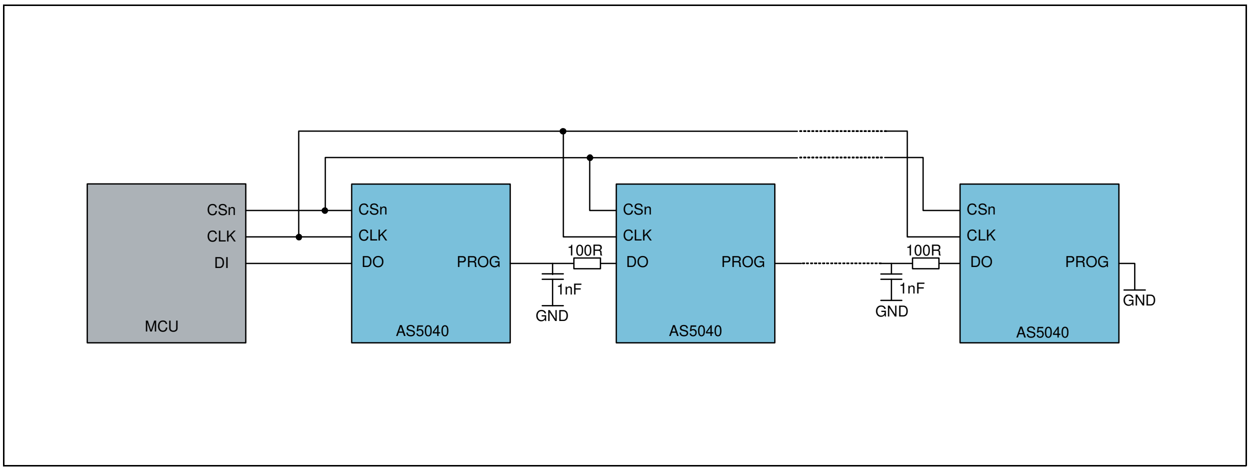
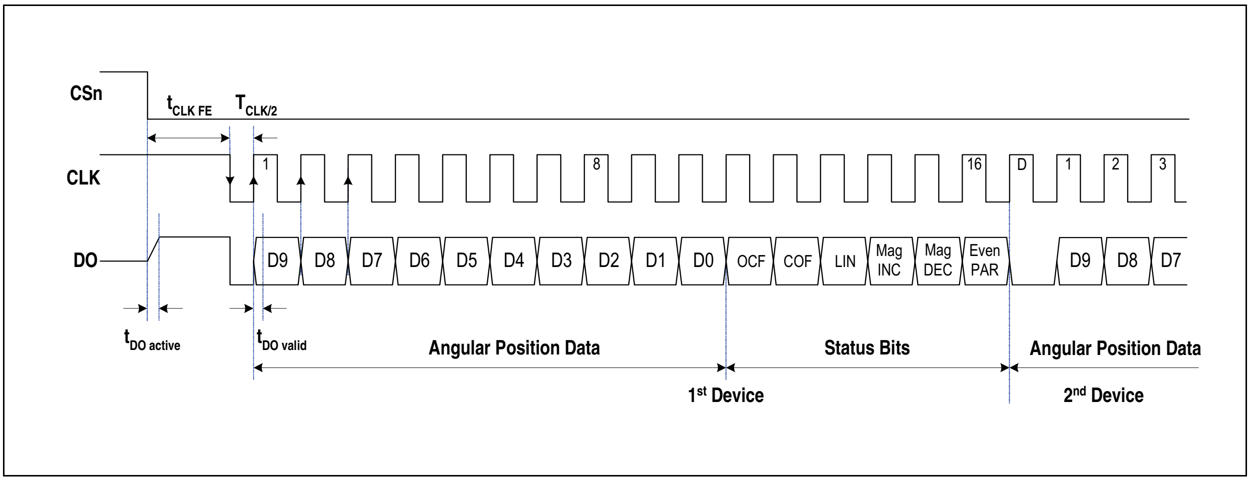


Figure 25:
Daisy Chain Mode Data Transfer



Incremental Outputs

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

Figure 26 shows the two-channel quadrature as well as the step/direction incremental signal (LSB) and the direction bit in clockwise (CW) and counter-clockwise (CCW) direction.

Quadrature A/B Output (Quad A/B Mode)

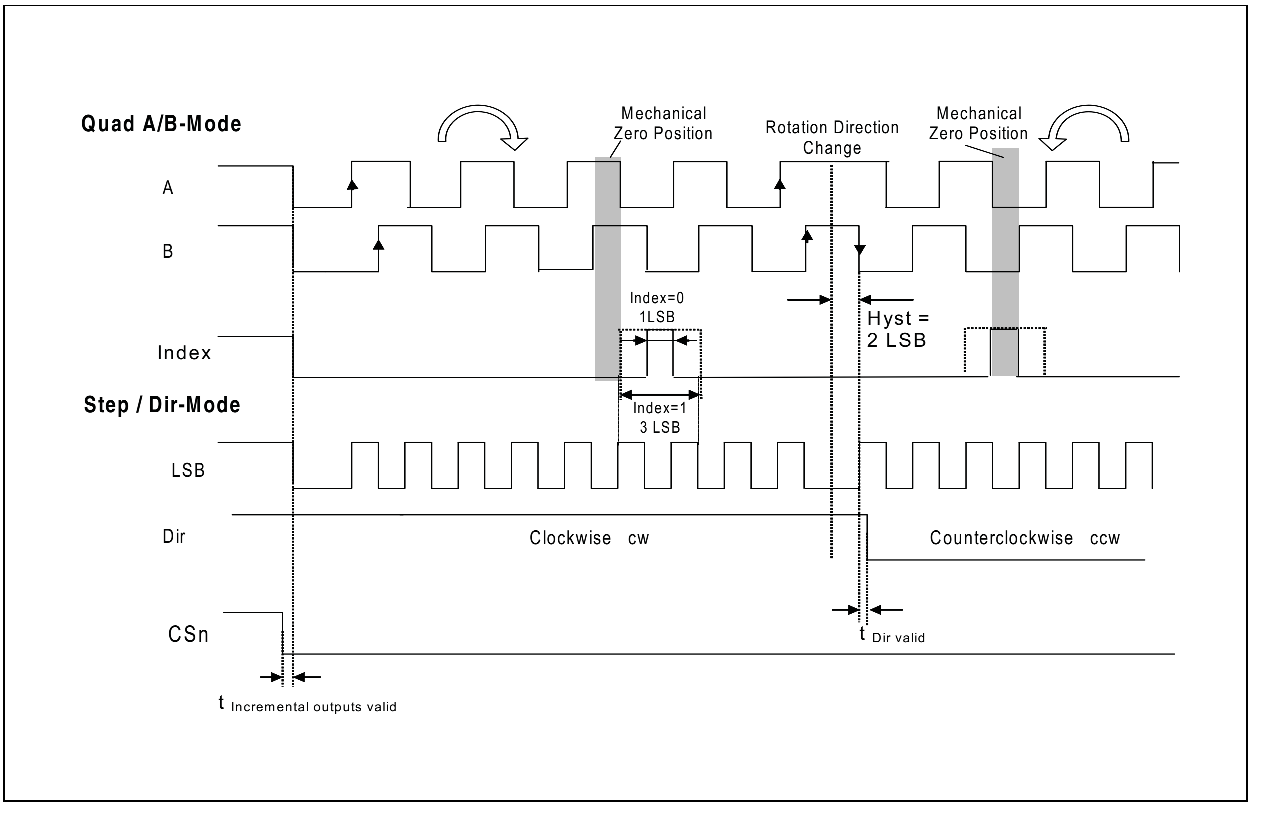
The phase shift between channel A and B indicates the direction of the magnet movement. Channel A leads channel B at a clockwise rotation of the magnet (top view) by 90 electrical degrees. Channel B leads channel A at a counter-clockwise rotation.

LSB Output (Step/Direction Mode)

Output LSB reflects the LSB (least significant bit) of the 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 view). Dir is updated with every LSB change.

In both modes (quad A/B, step/direction) 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 Figure 36).

Figure 26:
Incremental Output Modes



Incremental Power-Up Lock Option

After power-up, the incremental outputs can optionally be locked or unlocked, depending on the status of the CSn pin:

CSn = low at power-up:

> CSn has an internal pull-up resistor and must be externally pulled low ($R_{ext} \leq 5k\Omega$). If Csn is low at power-up, the incremental outputs (A, B, Index) will be high until the internal offset compensation is finished.
> This unique state (A=B=Index = high) may be used as an indicator for the external controller to shorten the waiting time at power-up. Instead of waiting for the specified maximum power up-time (0), the controller can start requesting data from the AS5040 as soon as the state (A=B=Index = high) is cleared.

CSn = high or open at power-up:

> In this mode, the incremental outputs (A, B, Index) will remain at logic high state, until CSn goes low or a low pulse is applied at CSn. This mode allows intentional disabling of the incremental outputs until for example the system microcontroller is ready to receive data.

Incremental Output Hysteresis

To avoid flickering incremental outputs at a stationary magnet position, a hysteresis is introduced.
In case of a rotational direction change, the incremental outputs have a hysteresis of 2 LSB.
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 all resolutions.
For constant rotational directions, every magnet position change is indicated at the incremental outputs (see Figure 27). 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. Following this direction, the incremental outputs will again be updated with every change of the magnet position.

Figure 27:
Hysteresis Window for Incremental Outputs