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AS5140H

10-Bit 360º Programmable Magnetic Rotary Encoder For High Ambient Temperatures

General Description

The AS5140H is a contactless magnetic rotary encoder for accurate angular measurement over a full turn of 360º and over an extended ambient temperature range of -40ºC to 150ºC.

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 0.35º = 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.

An internal voltage regulator allows the AS5140H to operate at either 3.3V or 5V supplies.

The AS5140H is pin-compatible to the AS5040; however it uses low-voltage OTP programming cells with additional programming options.

Ordering Information and Content Guide appear at end of datasheet.

Key Benefits & Features

The benefits and features of AS5140H, 10-Bit 360º Programmable Magnetic Rotary Encoder For High Ambient Temperatures are listed below:

Figure 1:
Added Value of Using AS5140H

Benefits	Features
No mechanical wear	Contactless high resolution rotational position encoding over a full turn of 360º
High resolution absolute position sensing	Two digital 10-bit absolute outputs: Serial interface and Pulse width modulated (PWM) output
Easy to use for motor control	Three incremental output modes: Quadrature A/B and Index output signal, Step / Direction and Index output signal, 3-phase commutation for brushless DC motors
Adjustable zero position	User programmable zero / index position

Benefits	Features
Tolerant to magnet misalignment	Failure detection mode for magnet placement monitoring and loss of power supply
Usable for high speed applications	Rotational speeds up to 10000 rpm
Tolerant to airgap variations	Pushbutton functionality detects movement of magnet in Z-axis
Supports daisy chain application	Serial read-out of multiple interconnected AS5140H devices using Daisy Chain mode
Fitting to automotive applications	Fully automotive qualified to AEC-Q100, grade 0
Operates up to 150°C ambient temperature	Wide ambient temperature range: -40ºC to 150ºC

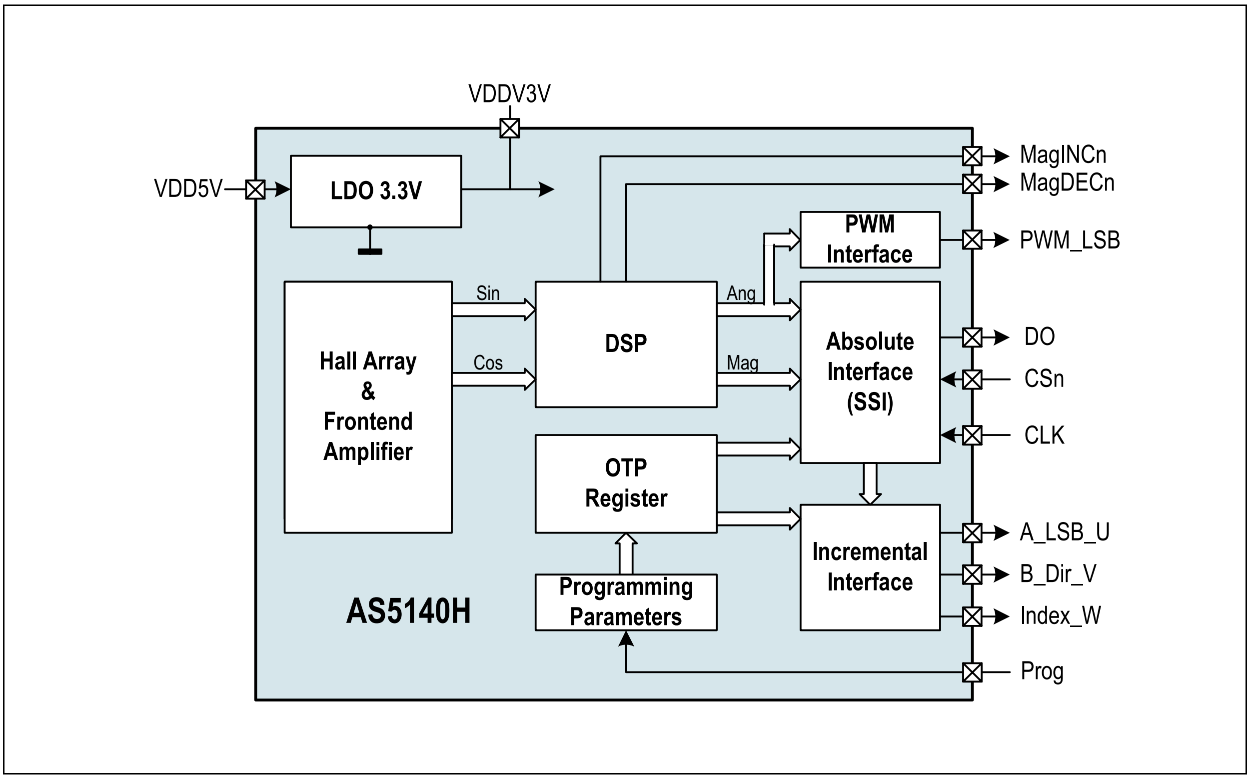
Applications

The AS5140H is an ideal solution for automotive applications like engine compartment sensors, transmission gearbox encoder, throttle valve position control and for industrial applications like rotary sensors in high temperature environment.

Block Diagram

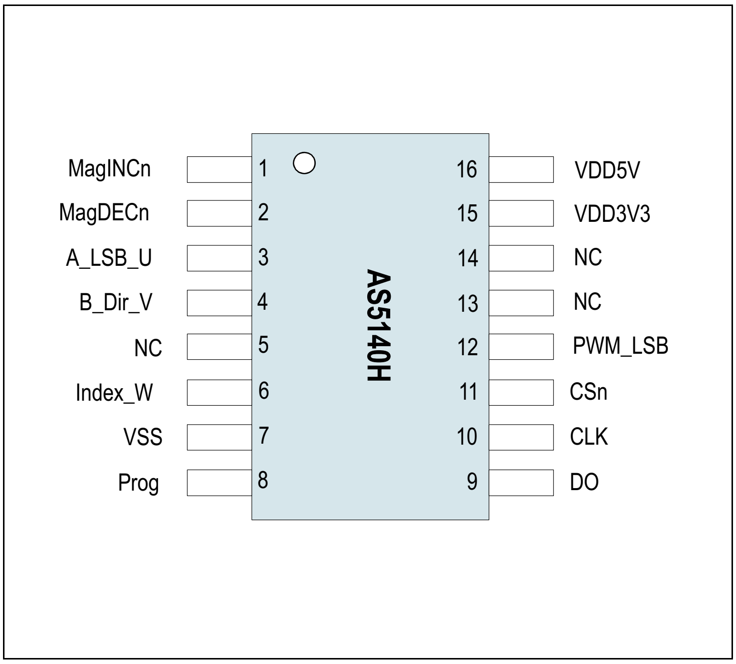
The functional blocks of this device for reference are shown below:

Figure 2:
AS5140H Block Diagram



Pin Assignment

Figure 3:
Pin Diagram (Top View)



Pin Description

The following figure 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 3).

Figure 4:
Pin Description

Pin Number	Pin Name	Description
1	MagINCn	**Magnet Field Magnitude Increase.** Active low. Indicates a distance reduction between the magnet and the device surface.
2	MagDECn	**Magnet Field Magnitude Decrease.** Active low. Indicates a distance increase between the device and the magnet.
3	A_LSB_U	**Mode1.x:** Quadrature A channel **Mode2.x:** Least Significant Bit **Mode3.x:** U signal (phase1)
4	B_Dir_V	**Mode1.x:** Quadrature B channel quarter period shift to channel A **Mode2.x:** Direction of Rotation **Mode3.x:** V signal (phase2)
5	NC	For internal use. Must be left unconnected.
6	Index_ W	**Mode1.x and Mode2.x:** Index signal indicates the absolute zero position **Mode3.x**: W signal (phase3)

Pin Number	Pin Name	Description
7	VSS	Negative Supply Voltage (GND).
8	Prog	**OTP Programming 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	**Data Output** of Synchronous Serial Interface.
10	CLK	**SSI Clock Input.** Schmitt-Trigger input.
11	CSn	**Chip Select.** Active low; Schmitt-Trigger input, internal pull-up resistor (~50kΩ) connect to VSS in incremental mode (see Incremental Power-up Lock Option on page 21)
12	PWM_LSB	Pulse Width Modulation of approx. 1kHz; LSB in Mode3.x
13	NC	For internal use. Must be left unconnected.
14	NC	For internal use. Must be left unconnected.
15	VDD3V3	3V-Regulator Output (see Figure 38)
16	VDD5V	Positive Supply Voltage 5V

Pin 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 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.

Note(s): 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 AS5140H 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 (see Incremental Mode Programming). This pin is also used as digital input to shift serial data through the device in Daisy Chain configuration, (see Figure 24).
- Pin 11 Chip Select (CSn; active low) selects a device within a network of AS5140H 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 (see Alignment Mode) and programming mode (see Programming the AS5140H).
- 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.

Absolute Maximum Ratings

Stresses beyond those listed in Absolute maximum Ratings may cause permanent damage to the device. These are stress ratings only, and 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 6:
Absolute Maximum Ratings

Parameter	Min	Max	Units	Comments
DC supply voltage at pin VDD5V	-0.3	7	V	
DC supply voltage at pin VDD3V3	-0.3	5	V	
Input pin voltage	-0.3	7	V	Pins Prog, MagINCn, MagDECn, CLK, CSn
Input current (latchup immunity)	-100	100	mA	Norm: JEDEC 78
Electrostatic discharge	± 2		kV	Norm: MIL 883 E method 3015
Storage temperature	-55	150	ºC	
Body temperature (Lead-free package)		260	ºC	t=20 to 40s, Norm: IPC/JEDEC J-Std-020C Lead finish 100% Sn "matte tin"
Humidity non-condensing	5	85	%	
Ambient temperature	-40	150	ºC	
Moisture Sensitivity Level (MSL)	3			Represents a maximum floor time of 168h

Electrical Characteristics

T_{AMB} = -40 to 150°C, VDD5V = 3.0-3.6V (3V operation)
VDD5V = 4.5-5.5V (5V operation) unless otherwise noted.

Figure 7:
Operating Conditions

Symbol	Parameter	Condition	Min	Typ	Max	Unit
I_{supp}	Supply current			16	21	mA
VDD5V	External supply voltage at pin VDD5V	5V operation	4.5	5.0	5.5	V
VDD3V3	Internal regulator output voltage at pin VDD3V3	5V operation	3.0	3.3	3.6	V
VDD5V	External supply voltage at pin VDD5V, VDD3V3	3.3V operation (pins VDD5V and VDD3V3 connected)	3.0	3.3	3.6	V
VDD3V3			3.0	3.3	3.6	V
t_{pwrup3}	External VDD3V3 supply voltage rise time at power-up	10-90% level in 3.3V mode (pins VDD5V and VDD3V3 connected)	1		150	µs

DC Characteristics for Digital Inputs and Outputs

Figure 8:
CMOS Schmitt-Trigger Inputs: CLK, CSn (CSn = Internal Pull-up)

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

Figure 9:
CMOS / Program Input: Prog

Symbol	Parameter	Condition	Min	Typ	Max	Unit
V_{IH}	High level input voltage		0.7 *VDD5V		5	V
V_{PROG}	High level input voltage	During programming	Refer to Programming Conditions			V
V_{IL}	Low level input voltage				0.3 *VDD5V	V
I_{iL}	Pull-up high level input current	VDD5V:5.0V			100	µA

Figure 10:
CMOS Output Open Drain: MagINCn, MagDECn

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

Figure 11:
CMOS Output: A, B, Index, PWM

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

Figure 12:
Tristate CMOS Output: DO

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

Magnetic Input Specification

Figure 13:
Electrical Characteristics

Symbol	Parameter	Condition	Min	Typ	Max	Unit
Magnetic Input Specification (Two-pole cylindrical diametrically magnetized source)						
d_{mag}	Diameter	Recommended magnet: Ø 6mm x 2.5mm for cylindrical magnets	4	6		mm
t_{mag}	Thickness		2.5			
B_{pk}	Magnetic input field amplitude	Required vertical component of the magnetic field strength on the die's surface, measured along a concentric circle with a radius of 1.1mm	45		75	mT
B_{OFF}	Magnetic offset	Constant magnetic stray field			± 10	mT
	Field non-linearity	Including offset gradient			5	%
f_{mag_abs}	Input frequency (rotational speed of magnet)	Absolute mode: 600 rpm @ readout of 1024 positions (see Figure 33)			10	Hz
		Incremental mode: no missing pulses at rotational speeds of up to 10000 rpm (see Figure 33)			166	
Disp	Displacement radius	Max. X-Y offset between defined IC package center and magnet axis (see Figure 40)			0.25	mm
		Max. X-Y offset between chip center and magnet axis			0.485	

Symbol	Parameter	Condition	Min	Typ	Max	Unit
	Chip placement tolerance	Placement tolerance of chip within IC package (see Figure 42)			±0.235	mm
	Recommended magnet material and temperature drift	NdFeB (Neodymium Iron Boron)		-0.12		%/K
		SmCo (Samarium Cobalt)		-0.035		

Electrical System Specifications

Figure 14:
Electrical System Specifications

Symbol	Parameter	Condition	Min	Typ	Max	Unit
RES	Resolution[1]	0.352 deg			10	bit
LSB	7 bit	Adjustable resolution only available for incremental output modes; Least significant bit, minimum step		2.813		deg
	8 bit			1.406		
	9 bit			0.703		
	10 bit			0.352		
INL_{opt}	Integral non-linearity (optimum)[2]	Maximum error with respect to the best line fit. Verified at optimum magnet placement, T_{AMB} =25°C			±0.5	deg
INL_{temp}	Integral non-linearity (optimum)	Maximum error with respect to the best line fit. Verified at optimum magnet placement, T_{AMB} = -40°C to 150°C			±0.9	deg
INL	Integral non-linearity	Best line fit = (Err_{max} – Err_{min}) / 2 Over displacement tolerance with 6mm diameter magnet, TAMB = -40°C to 150°C (see Figure 19)			±1.4	deg
DNL	Differential non-linearity[3]	10bit, no missing codes			±0.176	deg
TN	Transition noise[4]	RMS equivalent to 1 sigma			0.12	Deg RMS
Hyst	Hysteresis	Incremental modes only		0.704		deg

Symbol	Parameter	Condition	Min	Typ	Max	Unit
V_{ON}	Power-on reset thresholds On voltage; 300mV typ. hysteresis	DC supply voltage 3.3V (VDD3V3)	1.37	2.2	2.9	V
V_{OFF}	Power-on reset thresholds OFF voltage; 300mV typ. hysteresis		1.08	1.9	2.6	
t_{PwrUp}	Power-up time	Until offset compensation finished			50	ms
t_{delay}	System propagation delay absolute output	Includes delay of ADC and DSP			48	µs
	System propagation delay incremental output	Calculation over two samples			192	µs
f_S	Sampling rate for absolute output	Internal sampling rate, T_{AMB} = 25ºC	9.90	10.42	10.94	kHz
		Internal sampling rate, T_{AMB} = -40ºC to 150ºC	9.38	10.42	11.46	
CLK	Read-out frequency	Max. clock frequency to read out serial data			1	MHz

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

1. Digital Interface.
2. Integral Non-Linearity (INL) is the maximum deviation between actual position and indicated position.
3. Differential Non-Linearity (DNL) is the maximum deviation of the step length from one position to the next.
4. Transition Noise (TN) is the repeatability of an indicated position.

Programming Conditions

T_{AMB} = -40°C to 150°C, VDD5V = 3.0-3.6V (3V operation) VDD5V = 4.5-5.5V (5V operation), unless otherwise noted.

Figure 15:
Programming Conditions

Symbol	Parameter	Condition	Min	Typ	Max	Unit
V_{PROG}	Programming voltage	Voltage applied during programming	3.0	3.3	3.6	V
$V_{ProgOFF}$	Programming voltage OFF level	Line must be discharged to this level	0		1	V
I_{PROG}	Programming current	Current during programming			100	mA
$R_{programmed}$	Programmed fuse resistance (log 1)	10µA max. current @ 100mV	100k			Ω
$R_{unprogrammed}$	Unprogrammed fuse resistance (log 0)	2mA max. current @ 100mV	50		100	Ω
t_{PROG}	Programming time per bit	Time to prog. a single fuse bit	10		20	µs
t_{CHARGE}	Refresh time per bit	Time to charge the cap after t_{PROG}	1			µs
f_{LOAD}	LOAD frequency	Data can be loaded at n*2µs			500	kHz
f_{READ}	READ frequency	Read the data from the latch			2.5	MHz
f_{WRITE}	WRITE frequency	Write the data to the latch			2.5	MHz

Timing Characteristics

T_{AMB} = -40 to 150 °C, VDD5V = 3.0 to 3.6V (3V operation)
VDD5V = 4.5 to 5.5V (5V operation), unless otherwise noted

Figure 16:
Synchronous Serial Interface (SSI)

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

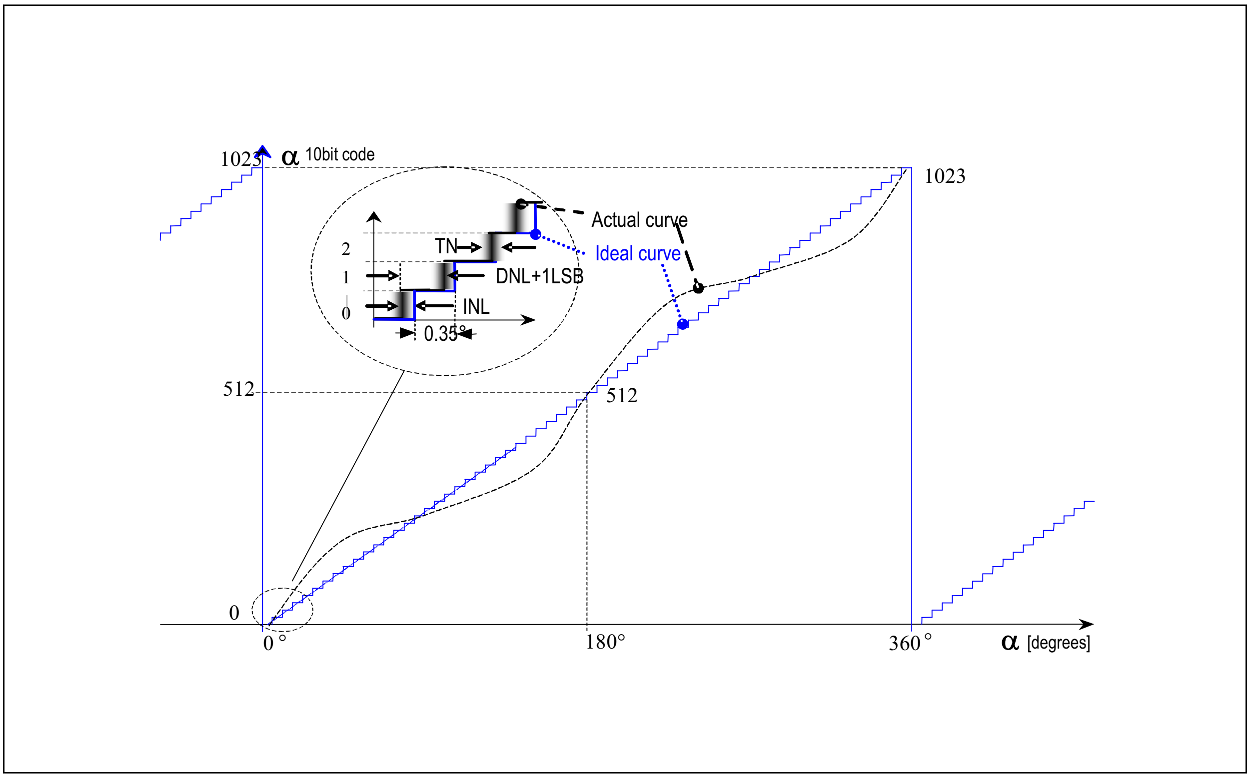
Figure 17:
Pulse Width Modulation Output

Symbol	Parameter	Conditions	Min	Typ	Max	Units
f_{PWM}	PWM frequency	Signal period = 1025µs ±5% at T_{AMB} = 25°C	0.927	0.976	1.024	kHz
		Signal period =1025µs ±10% at T_{AMB} = -40°C to 150°C	0.878	0.976	1.074	
PW_{MIN}	Minimum pulse width	Position 0d; angle 0 degree	0.90	1	1.10	µs
PW_{MAX}	Maximum pulse width	Position 1023d; angle 359.65 degree	922	1024	1126	µs

Figure 18:
Incremental Outputs

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

Figure 19:
Integral and Differential Non-Linearity Example (Exaggerated Curve)



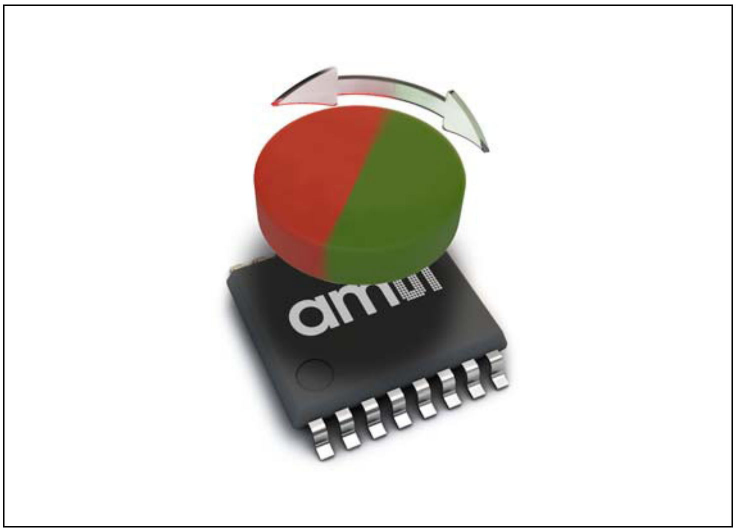
Detailed Description

The AS5140H 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 AS5140H 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 39).

The AS5140H 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). Simultaneously, the device also provides incremental output signals. The various incremental output modes can be selected by programming the OTP mode register bits (see Figure 35). 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. 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 AS5140H is tolerant to magnet misalignment and magnetic stray fields due to differential measurement technique and Hall sensor conditioning circuitry.

Figure 20:
Typical Arrangement of AS5140H and Magnet



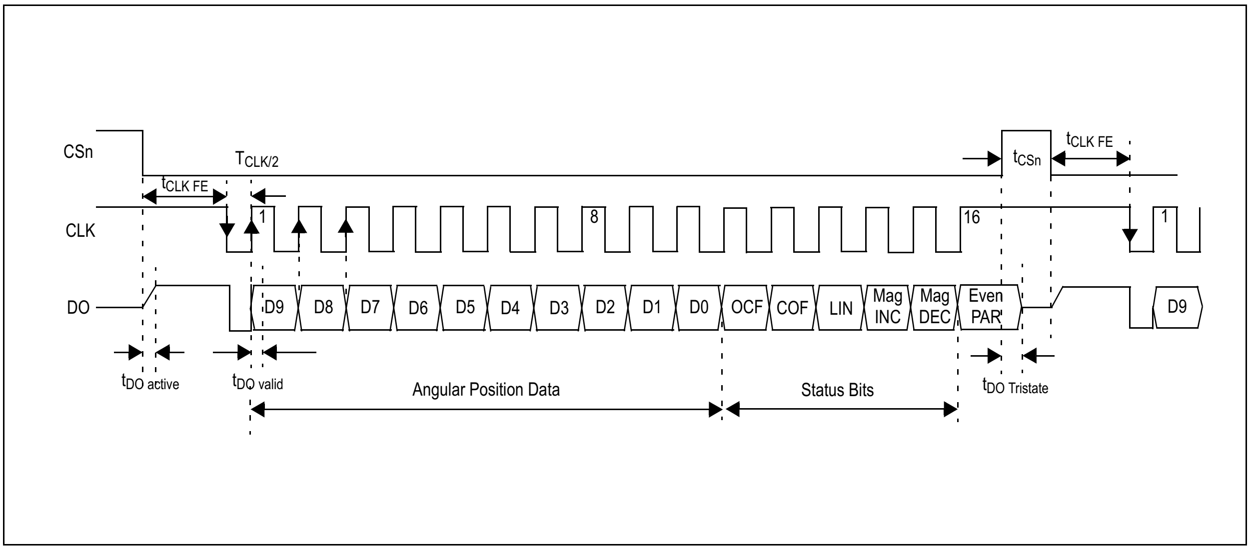
10-Bit Absolute Angular Position Output

Synchronous Serial Interface (SSI)

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}.

Figure 21:
Synchronous Serial Interface with Absolute Angular Position Data



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. For fast startup, this bit may be polled by the external microcontroller. As soon as this bit is set, the AS5140H has completed the startup and the data is valid (see Figure 23).

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

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

Signal "HIGH" for both MagINCn and MagDECn indicate a magnetic field that is out of the allowed range (see Figure 22).

Figure 22:
Magnetic Magnitude Variation Indicator

MagINCn	MagDECn	Description
0	0	No distance change Magnetic Input Field OK (in range)
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: Too large, too small (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 – A bit for transmission error detection of bits 1to 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	MagINCn	MagDECn	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 600rpm. Readout of every second angular position allows for rotational speeds of up to 1200 rpm.

Consequently, increasing the rotational speed reduces the number of absolute angular positions per revolution (see Figure 45). 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 10000 rpm without missing pulses.

Daisy Chain Mode

The Daisy Chain mode allows connection of several AS5140H'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. 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,

(EQ1) $n * (16+1)$ *bits*

For example, 34 bits for two devices, 51 bits 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).

Figure 24:
Daisy Chain Hardware Configuration

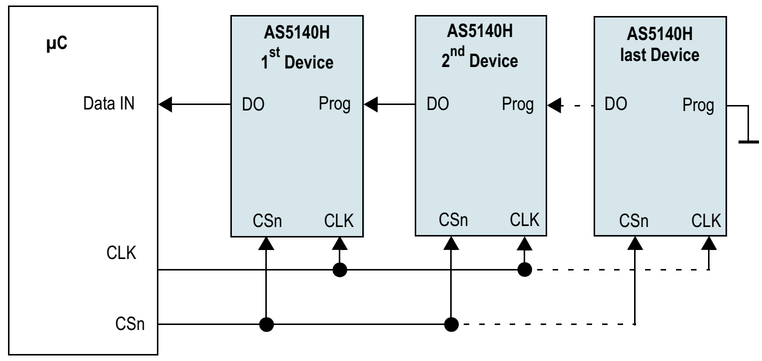
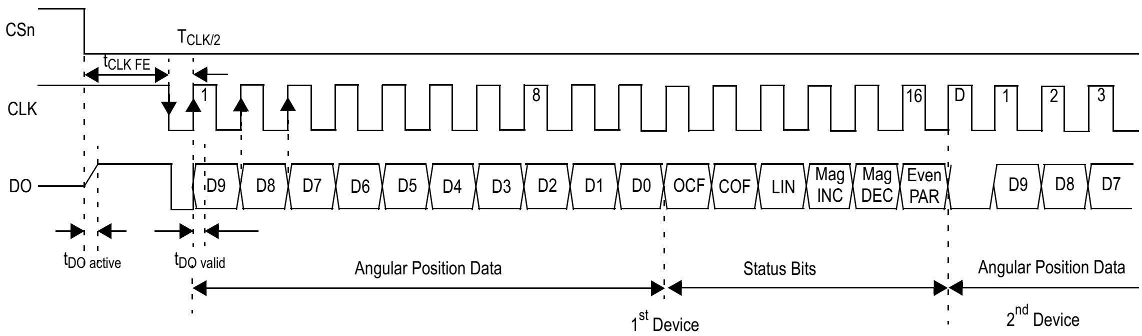


Figure 25:
Daisy Chain Mode Data Transfer



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 AS5140H), 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.

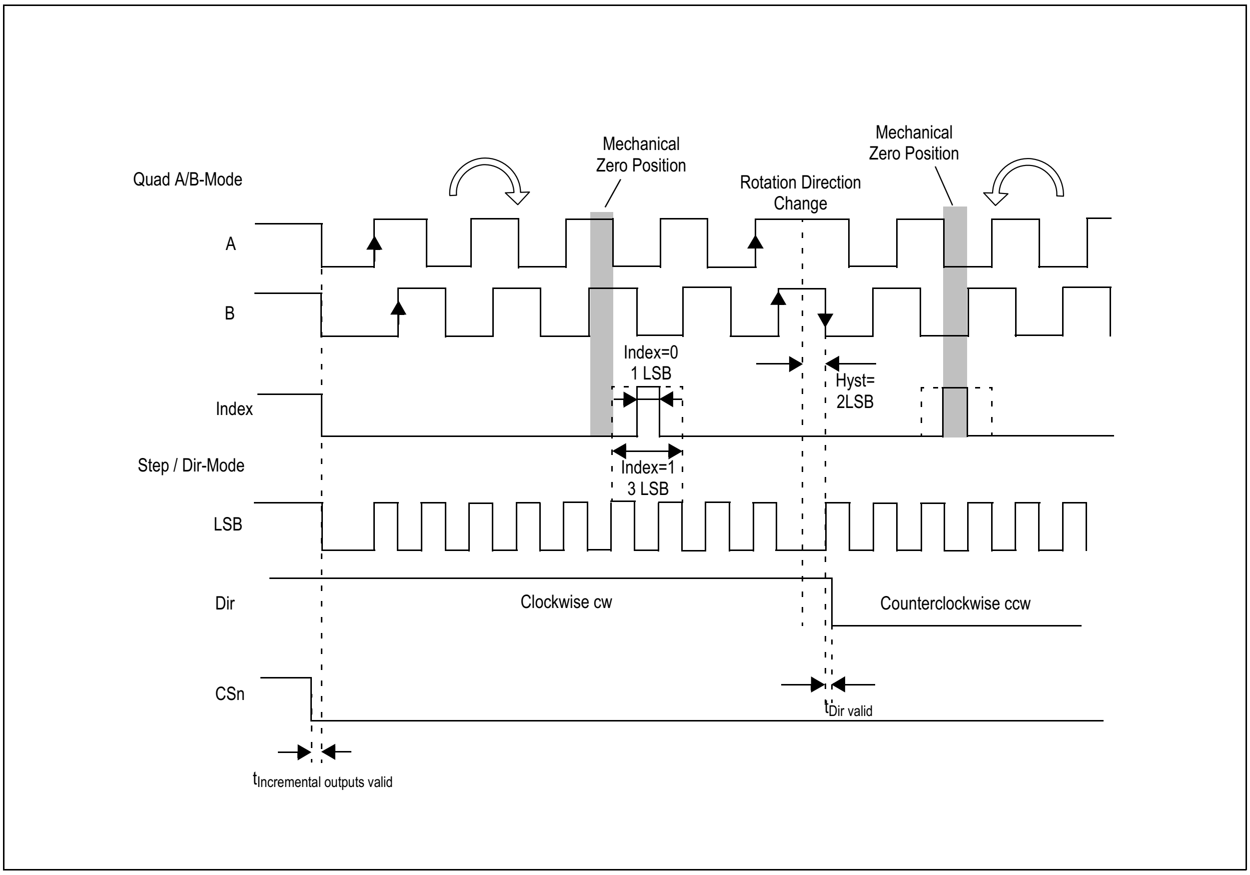
Incremental Outputs

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.

Figure 26:
Incremental Output Modes



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 (seeFigure 35).

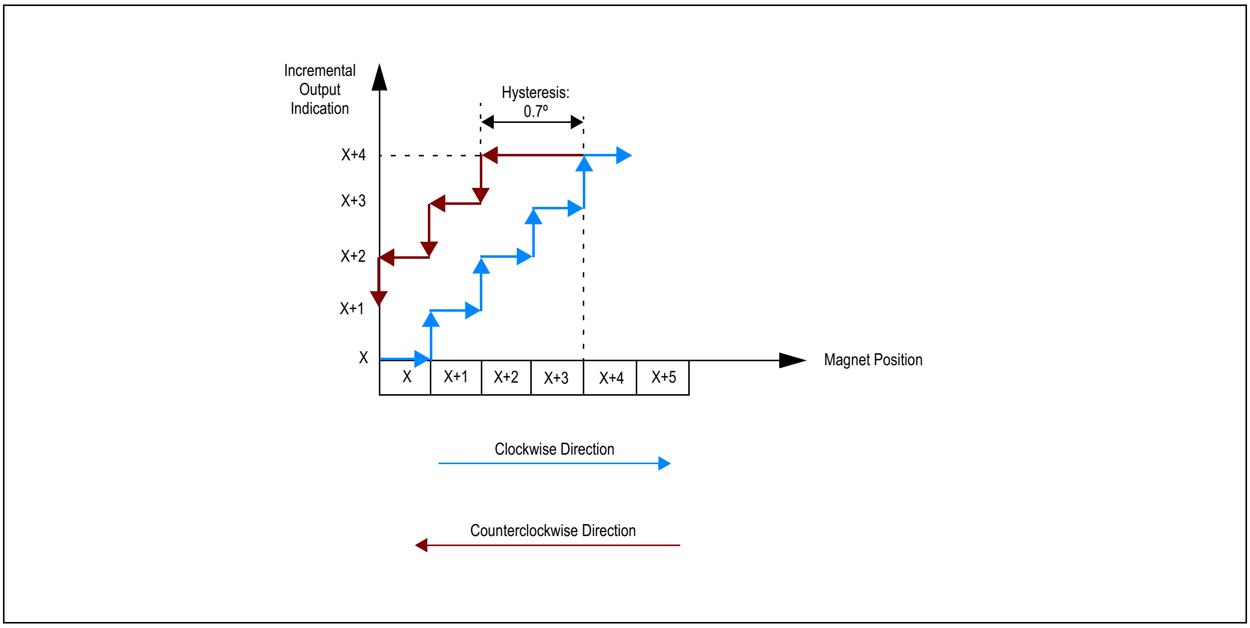
Incremental Power-up Lock Option. After power-up, the incremental outputs can optionally be locked or unlocked, depending on the status of the CSn pin:

- 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 AS5140H 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). For example, if 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



Pulse Width Modulation (PWM) Output

The AS5140H provides a pulse width modulated output (PWM), whose duty cycle is proportional to the measured angle:

$$\text{Position} = \frac{t_{ON} \cdot 1025}{(t_{ON} + t_{OFF})} - 1 \quad \text{(EQ2)}$$

The PWM frequency is internally trimmed to an accuracy of ±5% (±10% over full temperature range). This tolerance can be cancelled by measuring the complete duty cycle as shown above.

Figure 28:
PWM Output Signal

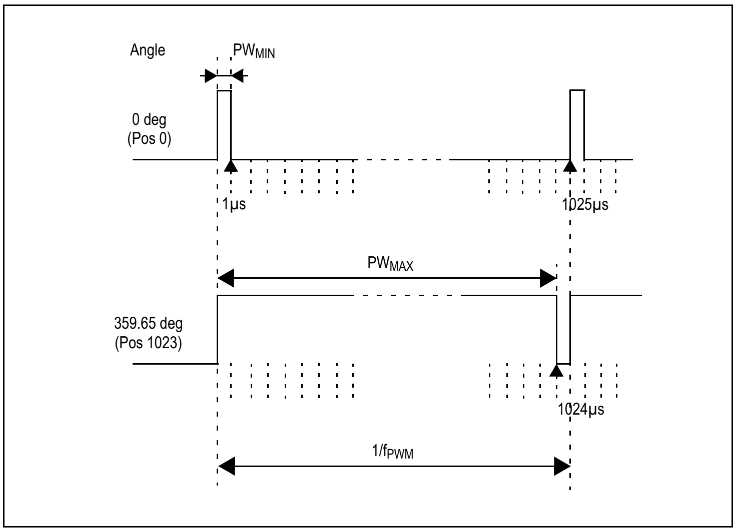


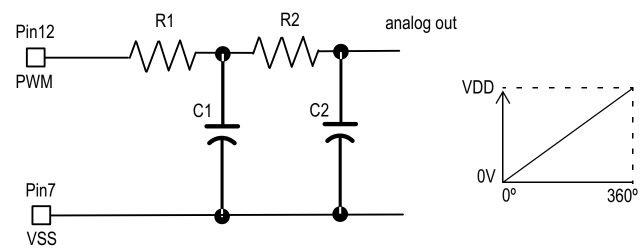
Figure 29:
PWM Signal Parameters

Symbol	Parameter	Typ	Unit	Note
f_{PWM}	PWM frequency	0.9756	kHz	Signal period: 1025µs
PW_{MIN}	MIN pulse width	1	µs	Position 0d Angle 0 deg
PW_{MAX}	MAX pulse width	1024	µs	Position 1023d Angle 359.65 deg

Analog Output

An analog output may be generated by averaging the PWM signal, using an external active or passive lowpass filter. The analog output voltage is proportional to the angle: 0º = 0V; 360º = VDD5V. Using this method, the AS5140H can be used as direct replacement of potentiometers.

Figure 30:
Simple Passive 2nd Order Lowpass Filter



(EQ3) *R1, R2 ≥ 4k7   C1, C2 ≥ 1µF/6V*

R1 should be ≥4k7 to avoid loading of the PWM output. Larger values of Rx and Cx will provide better filtering and less ripple, but will also slow down the response time.

Brushless DC Motor Commutation Mode

Brushless DC motors require angular information for stator commutation. The AS5140H provides U-V-W commutation signals for one and two pole pair motors. In addition to the three-phase output signals, the step (LSB) output at pin 12 allows high accuracy speed measurement. Two resolutions (9 or 10 bit) can be selected by programming Div0 according to Figure 35.

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 31and Figure 32) is calculated by multiplying each transition position by the angular value of 1 count:

(EQ4) $$Angle[deg] = Position\ x\ (360\ degree/1024)$$

Figure 31:
U, V and W-Signals for BLDC Motor Commutation (Div1=0, Div0=0)

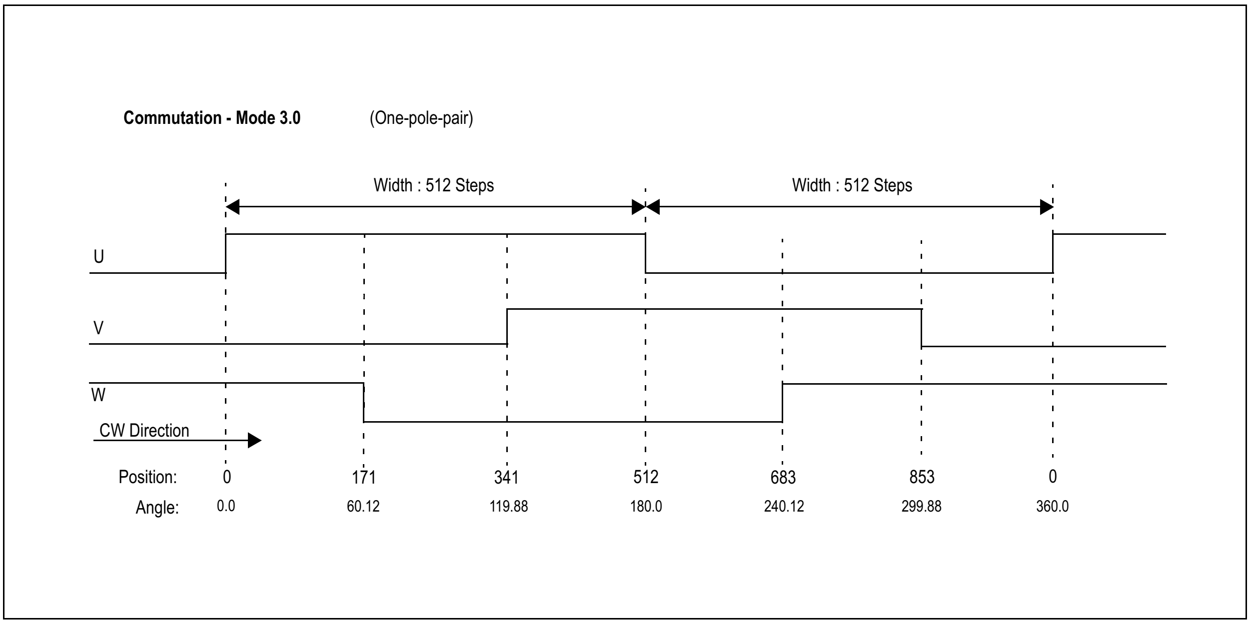
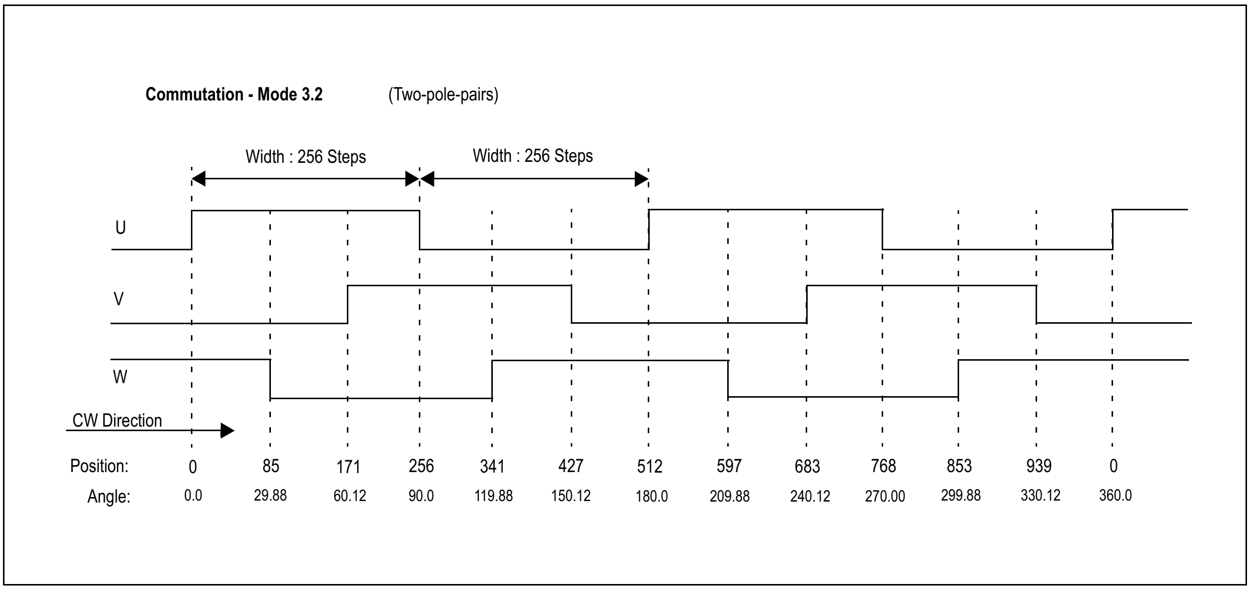


Figure 32:
U, V and W-Signals for 2Pole BLDC Motor Commutation (Div1=1, Div0=0)



Programming the AS5140H

Note(s): A detailed description of the **ams** low voltage polyfuse OTP programming method is given in Application Note AN514X-10, which can be downloaded from the **ams** website. The OTP programming description in this datasheet is for general information only.

After power-on, programming the AS5140H is enabled with the rising edge of CSn with Prog = high and CLK = low. The AS5140H programming is a one-time-programming (OTP) method, based on polysilicon fuses. The advantage of this method is that a programming voltage of only 3.3V is required for programming. The OTP consists of 52 bits, of which 21 bits are available for user programming. The remaining 31 bits contain factory settings and a unique chip identifier (Chip-ID).

A single OTP cell can be programmed only once. Per default, the cell is "0"; a programmed cell will contain a "1". While it is not possible to reset a programmed bit from "1" to "0", multiple OTP writes are possible, as long as only unprogrammed "0"-bits are programmed to "1". Independent of the OTP programming, it is possible to overwrite the OTP register temporarily with an OTP write command at any time. This setting will be cleared and overwritten with the hard programmed OTP settings at each power-up sequence or by a LOAD operation.