AS5011

Low Power Integrated Hall IC for Human Interface Applications

1 General Description

The AS5011 is a complete Hall Sensor IC for smart navigation key applications to meet the low power requirements and host SW integration challenges for products such as cell phones and smart handheld devices.

Due to the on chip processing engine, system designers are not tasked with integrating complex SW algorithms on their host processor thus leading to rapid development cycles.

The AS5011 single-chip IC includes 4 integrated Hall sensing elements for detecting up to ±2mm lateral displacement, high resolution ADC, XY coordinate and motion detection engine combined with a smart power management controller.

The X and Y positions coordinates and magnetic field information for each Hall sensor element is transmitted over a 2-wire serial interface to the host processor.

The AS5011 is available in a small 16-pin QFN (4x4x0.55mm) or 16-pin QFN (5x5x0.55mm) package and specified over an operating temperature of -20 to +80°C.

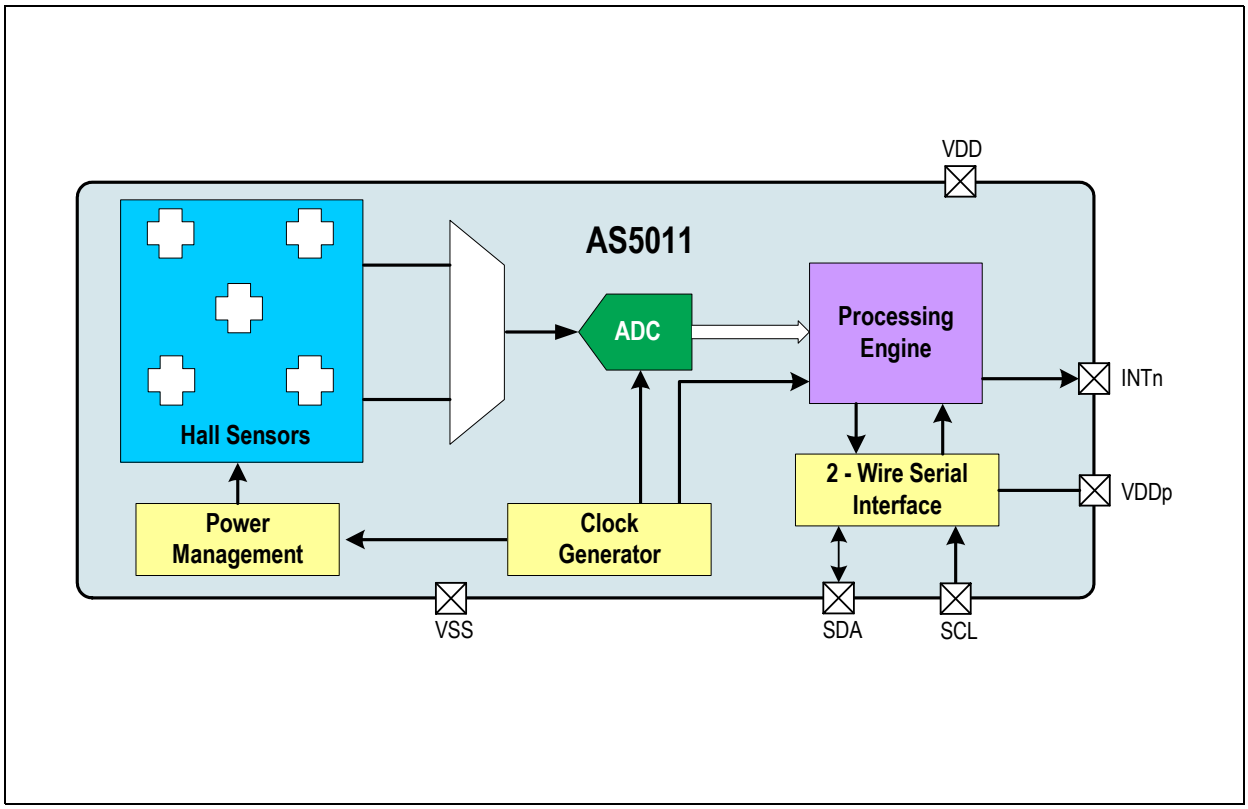
2 Key Features

- 2.7 to 3.6V operating voltage
- Down to 1.8V peripheral supply voltage
- Less than 200µA current consumption in Low Power mode
- Less than 50µA current consumption in Shutdown mode
- Lateral magnet movement radius up to 2mm
- 2-Wire serial interface up to 4MHz in Push-pull configuration
- Configurable interrupt output for motion detection
- Three operating modes:
  - Shutdown mode
  - Low Power mode
  - Full Power mode

3 Applications

The AS5011 is ideal for small form-factor manual input devices in battery operated equipment, such as Mobile phones, MP3 players, PDAs, GPS receivers and Gaming consoles.

Figure 1. AS5011 Block Diagram



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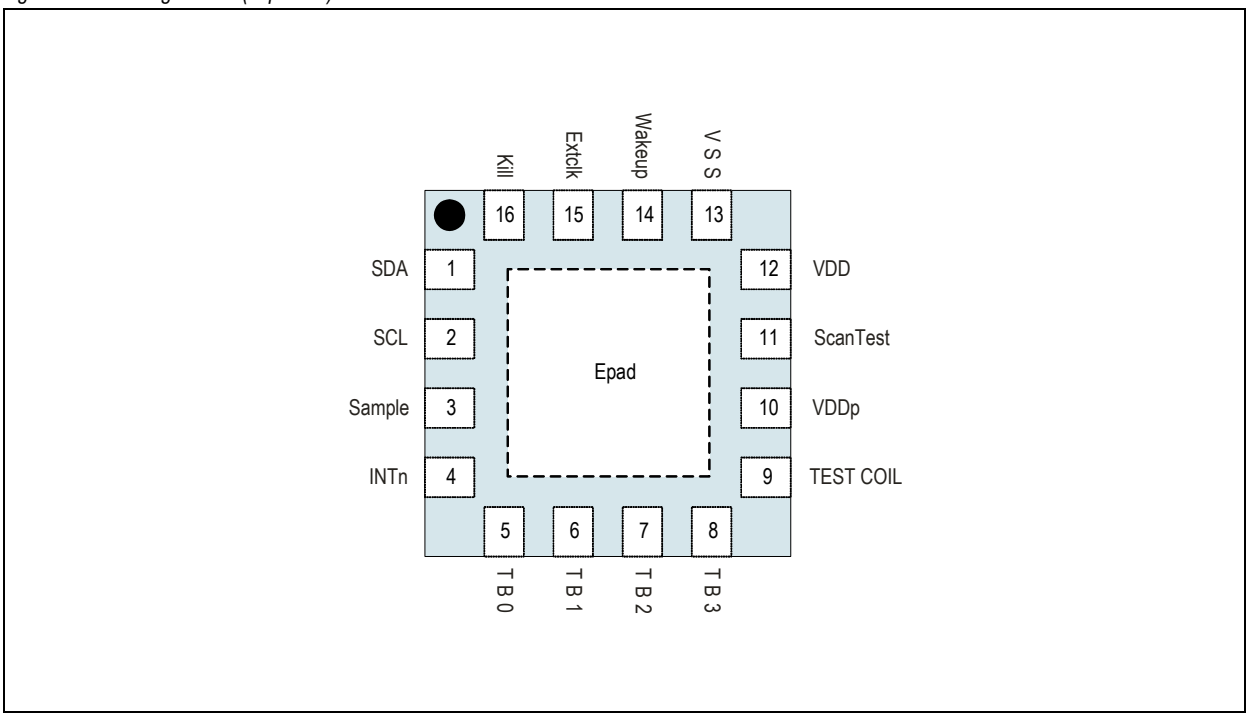
4 Pin Assignments

Figure 2. Pin Assignments (Top View)



4.1 Pin Descriptions

Table 1. Pin Descriptions

Pin Number	Pin Name	Pin Type	Description
1	SDA	Digital I/O / Open drain	2-Wire serial bus data
2	SCL	Digital input	2-Wire serial bus clock
3	Sample		Test pin. Connect to VSS
4	INTn	Digital output open drain	Interrupt output. Active LOW
5	TB0	Analog I/O	Test pin. Leave unconnected
6	TB1		Test pin. Leave unconnected
7	TB2		Test pin. Leave unconnected
8	TB3		Test pin. Leave unconnected
9	TEST COIL	-	Test pin. Connect to VSS
10	VDDp	Supply pad	Peripheral power supply, 1.8V ~ 3.6V
11	ScanTest	Digital input	Test pin. Connect to VSS
12	VDD	Supply pad	Core power supply, 2.7V ~ 3.6V
13	VSS		Supply ground
14	Wakeup	Digital I/O	Test pin. Leave unconnected
15	Extclk		Test pin. Leave unconnected
16	Kill		Test pin. Leave unconnected
EPAD	-	-	Center pad not connected

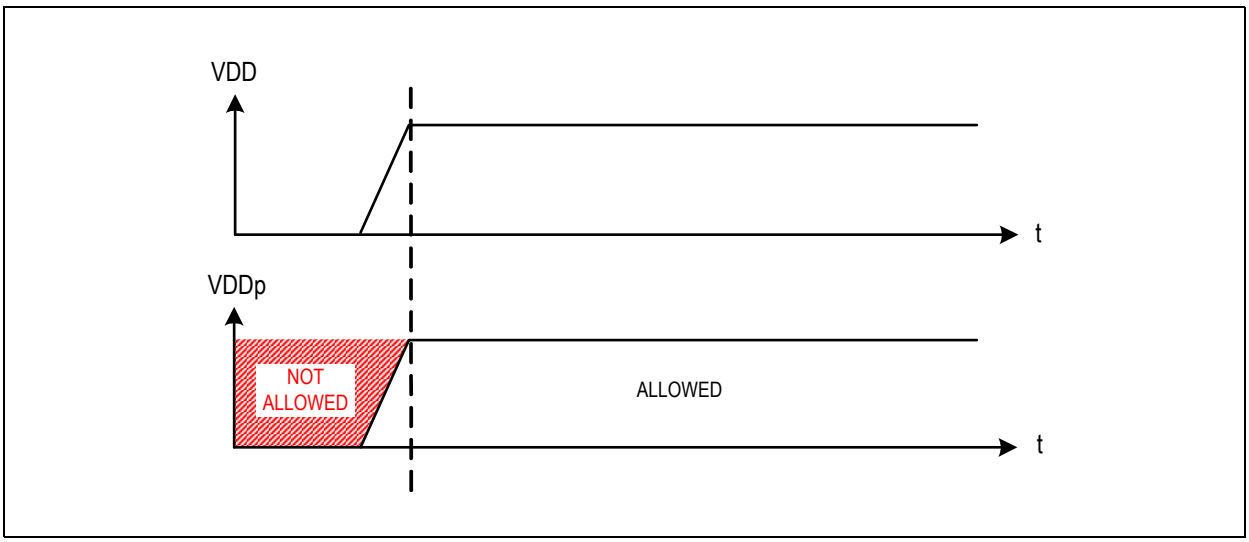
5 Absolute Maximum Ratings

Stresses beyond those listed in Table 2 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 on page 5 is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Table 2. Absolute Maximum Ratings

Symbol	Parameter	Min	Max	Units	Comments
Electrical Parameters					
VDD	DC supply voltage	-0.3	5	V	
VDDp	Peripheral supply voltage	-0.3	5 VDD +0.3	V	Maximum VDDp is whichever value that is lower: VDD+0.3V or 5V
V_{IN}	Input pin voltage	-0.3	VDDp +0.3	V	
		-	3.6		
I_{scr}	Input current (latchup immunity)	-100	100	mA	Norm: JEDEC 78
Electrostatic Discharge					
ESD	Electrostatic discharge	-	±1	kV	Norm: MIL 883 E method 3015
Temperature Ranges and Storage Conditions					
Θ_{JA}	Package Thermal Resistance	-	30	°C/W	Velocity=0, Multi Layer PCB; JEDEC Standard Testboard
P_t	Total power dissipation		36	mW	
T_{strg}	Storage temperature	-55	125	°C	
T_{body}	Package body temperature		260	°C	The reflow peak soldering temperature (body temperature) specified is in accordance with *IPC/JEDEC J-STD-020 "Moisture/Reflow Sensitivity Classification for Non-Hermetic Solid State Surface Mount Devices".* The lead finish for Pb-free leaded packages is matte tin (100% Sn).
	Humidity non-condensing	5	85	%	

Figure 3. Power-up Sequence[1]



1. Powering-up VDDp is only allowed at the same time or after VDD.

6 Electrical Characteristics

6.1 Operating Conditions

TAMB = -20°C to +80°C, VDD = 3.3V

Table 3. Operating Conditions

Symbol	Parameter	Min	Typ	Max	Units	Note
VDD	Core supply voltage	2.7		3.6	V	
VDDp	Peripheral supply voltage	1.8		VDD +0.3	V	Open drain outputs: SCL, SDA, INT/
IDD_s	Current consumption on core supply Shutdown mode			50	µA	Average current pin VDD Pulsed current IDDf during t_{conv} with period $t_{P,W}$
IDD_l	Current consumption on core supply Low Power mode			200	µA	Average current pin VDD Pulsed current IDDf during t_{conv} with period $t_{P,A}$
IDD_f	Current consumption on core supply Full Power mode			10	mA	Continuous current pin VDD
$t_{P,W}$	Polling clock rate Shutdown mode	65.6	80	94.4	ms	Internal
$t_{P,A}$	Polling clock rate Low Power mode	16.4	20	23.6	ms	Internal
t_{conv}	Coordinate conversion time	330	380	455	µs	Full Power mode
dx dy	Lateral movement radius	±1.8	2	±2.3	mm	Vertical magnetic field at magnet centre, measured at the chip surface[1]
d	Type of magnet	2		3	mm	Cylindrical; axial magnetized
RH	Hall array diameter		2.2		mm	
B_Z	Magnetic field strength	30		120	mT	Vertical magnetic field at magnet center; measured at chip surface
T_{amb}	Ambient temperature range	-20		+80	°C	
	Magnetic field measurement resolution		11		bit	Internal
	Resolution of XY displacement		8		bit	Over 2*dx and 2*dy axis
	IC package	QFN16 5x5x0.55mm QFN16 4x4x0.55mm				
	Power supply filtering capacitors	100			nF	Ceramic capacitor VDD – VSS
		100			nF	Ceramic capacitor VDDp – VSS

1. Depends on magnet and airgap.

6.2 Digital IO pads DC/AC Characteristics

Table 4. DC / AC Characteristics

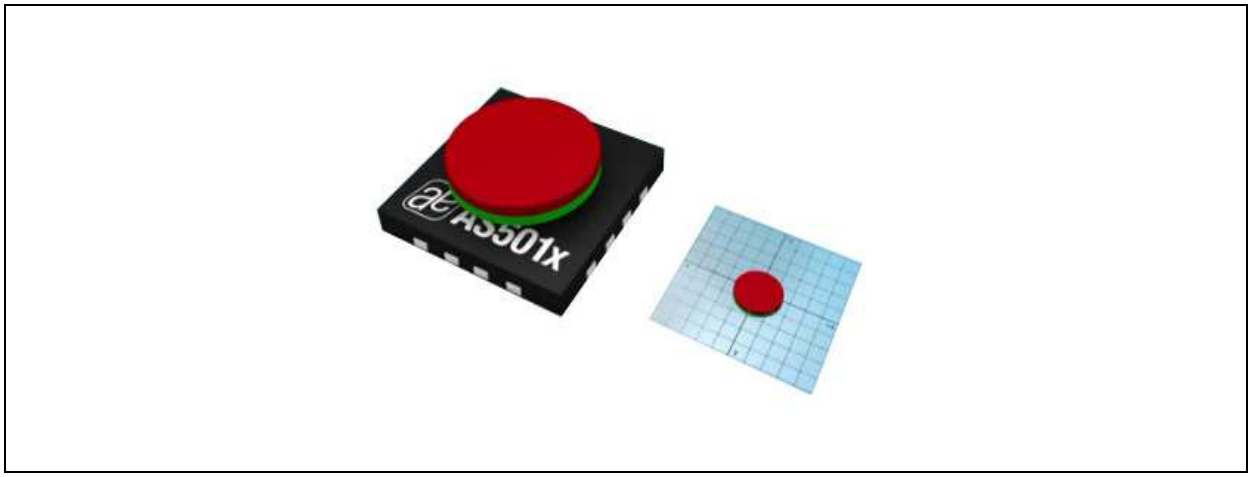
Symbol	Parameter	Min	Max	Unit	Note
Inputs: SCL, SDA (receiver)					
V_{IH}	High level input voltage	0.7 * VDDp		V	
V_{IL}	Low level input voltage		0.3 * VDDp	V	VDDp ≥ 2.7V
			0.25 * VDDp		VDDp < 2.7V
I_{LEAK}	Input leakage current		1	µA	VDDp = 3.6V
C_L	Capacitive load		35	pF	
Outputs: INTn, SDA (transmitter)					
V_{OH}	High level output voltage	Open drain			Leakage current 1 µA
V_{OL}	Low level output voltage		VSS + 0.4	V	-2mA

7 Detailed Description

The benefits of the AS5011 device are as follows:

- Complete system-on-chip
- High reliability due to non-contact sensing
- Low power consumption

Figure 4. Typical Arrangement of AS5011 and Axial Magnet



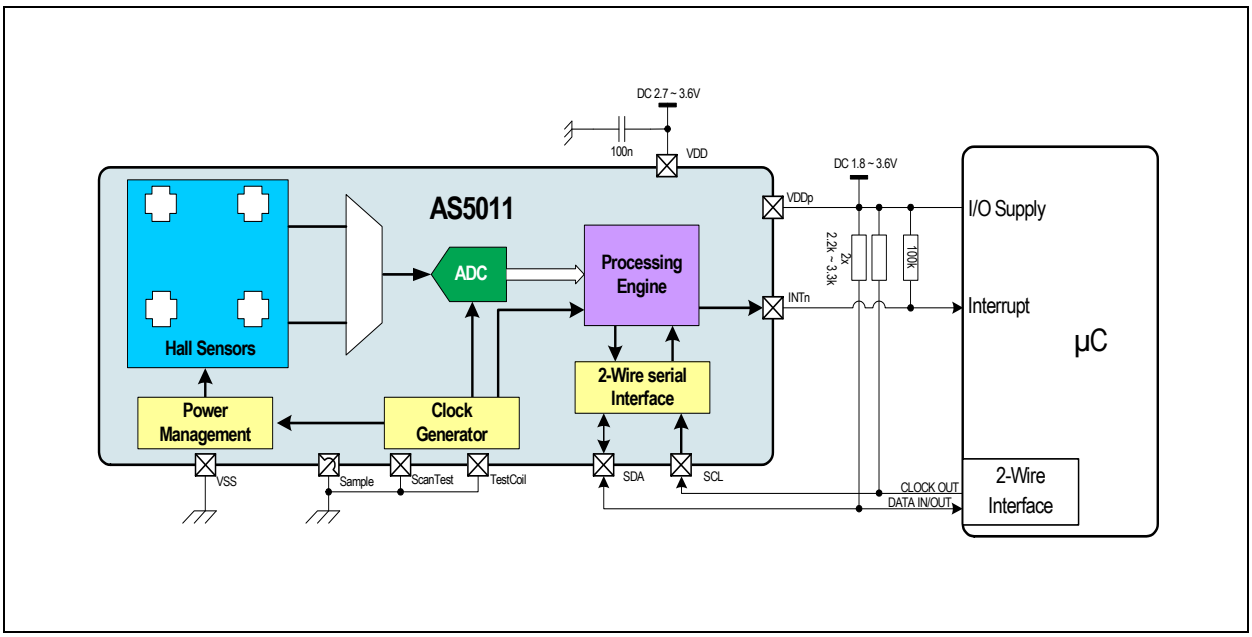
7.1 Operating the AS5011

Typical Application.

The AS5011 requires only a few external components in order to operate immediately when connected to the host microcontroller.

Only 4 wires are needed for a simple application using a single power supply: two wires for power and two wires for the 2-WIRE serial communication. A fifth connection can be added in order to send an interrupt to the host CPU when the magnet is moving away from the center and to inform that a new valid coordinate can be read.

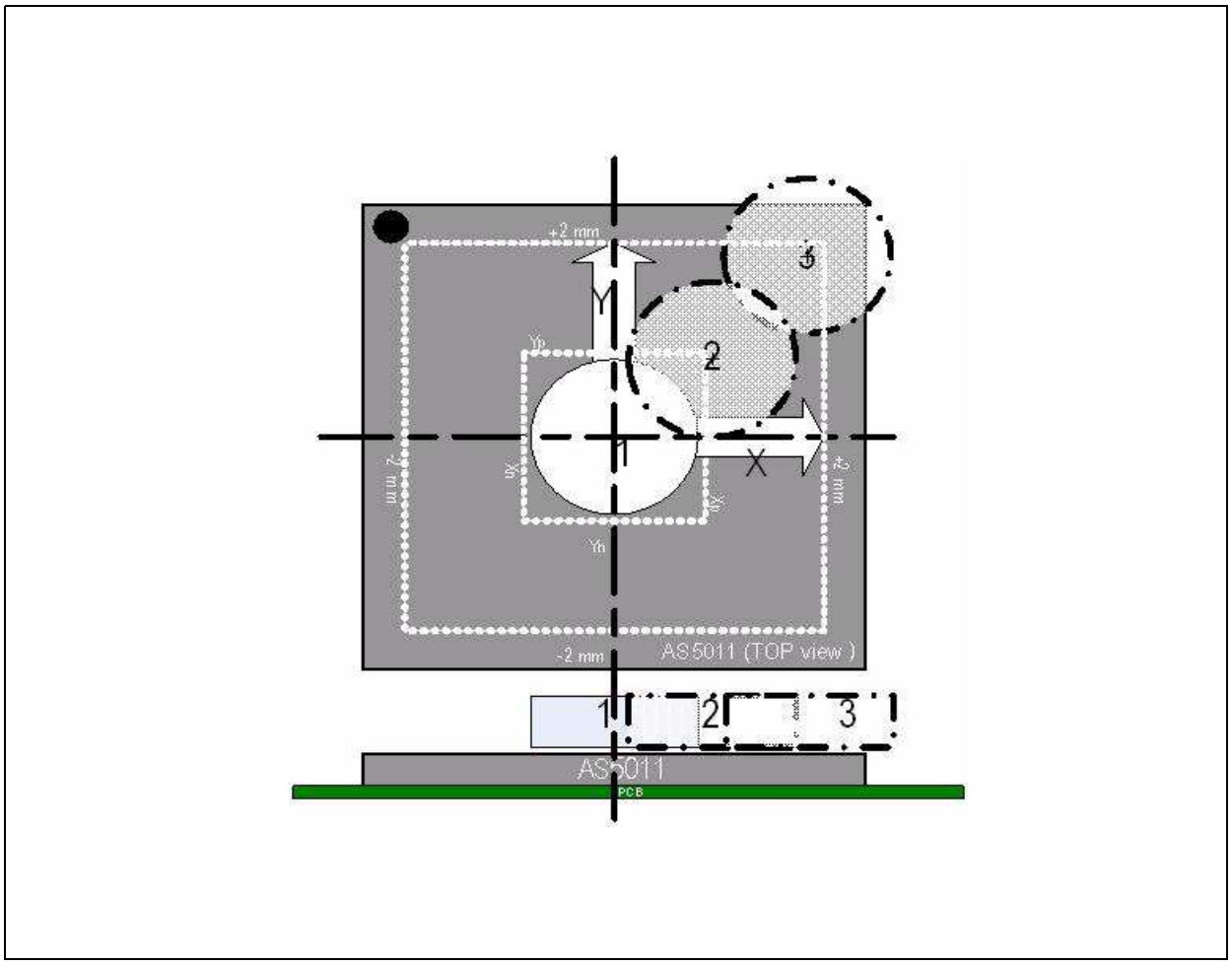
Figure 5. Electrical Connection of AS5011 with Microcontroller



7.2 XY Coordinates Interpretation

On Figure 6 the top view of the AS5011 is represented, with a round magnet (scaled) gliding over its surface. The magnet can be placed under the sensor too, with the PCB between them.

Figure 6. Position Range of the Magnet



Magnet on Position 1.

The magnet is in its initial position, centered on the sensor. The AS5011 is in Shutdown mode. X and Y register values are (0,0)

Magnet on Position 2.

The center of the magnet has been moved upon the horizontal wakeup threshold Xp. An interrupt is sent to the host microcontroller which sets the AS5011 to Low Power mode. Wakeup thresholds are programmable independently for the four directions.

Magnet on Position 3.

The magnet is at the X and Y limit over the sensor surface (2mm, 2mm) but still in range.

7.3 Magnet-chip Surface Airgap Range

The relation between the magnet physical position and the resulting XY registers depends on the magnet type/size/shape, and the airgap between the magnet and the top (or bottom) surface of the AS5011.

The measurements on Figure 7, Figure 8, Figure 9 have been processed with the AS5000-MA2H-1 d2x0.8mm cylinder magnet, available on austriamicrosystems website. For those magnets, used in EasyPoint modules EP40 and EP50, the airgap range is typically 0~3mm.

The following diagrams show the relation between the X register value and the physical X coordinate (±2mm horizontal displacement, 0mm is the center of the chip package) of the magnet at different airgaps. The resulting X value range decreases when the airgap increases

The Y axis measurements are the same as the X axis ones.

Figure 7. X Register/X Displacement (500µm Airgap)

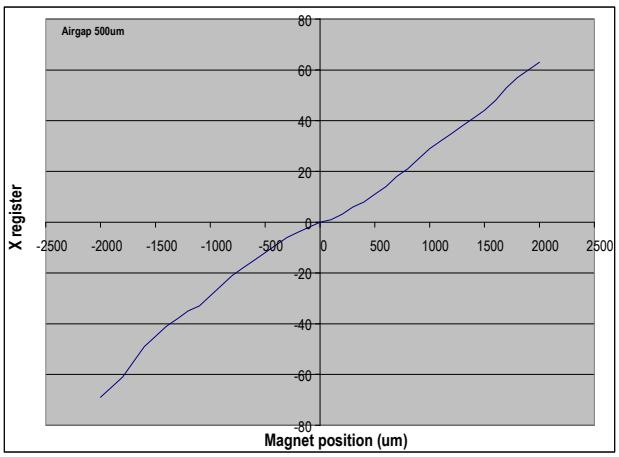


Figure 8. X Register/X Displacement (1500µm Airgap)

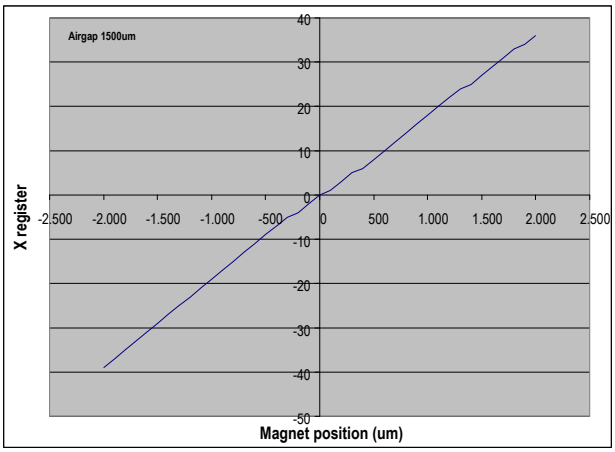
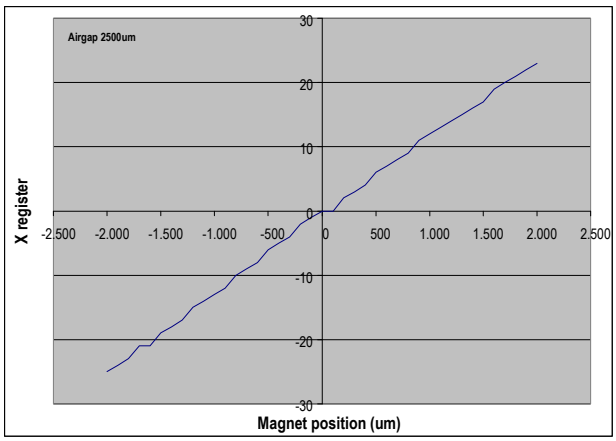


Figure 9. X Register/X Displacement (2500µm Airgap)



7.4 Power Modes

The AS5011 can operate in three different power modes, depending on the power consumption requirements of the whole system.

Table 5. Overview of Typical Power Modes

Power Mode	[0x76] Register	Description
Sleep phase		Power state between wakeups in Shutdown and Low Power modes RC clock and analog part OFF Digital part in static mode
Shutdown mode	*1001_x00x* LP_Pulsed = 1 LP_Active = 0 LP_Continue = 0 INT_wup_en = 1	Default mode after power on <50µA current consumption Wake up every 80ms from Sleep phase Hall elements in reduced power during wake up RC clock ON Interrupt LOW on INTn if the magnet is away from the center above the Xp Xn Yp Yn threshold values[1]
Low Power mode	*110x_100x* LP_Pulsed = 1 LP_Active = 1 LP_Continue = 0 INT_act_en = 1	<200µA current consumption Wake up every 20ms from Sleep phase Hall elements in high power during wake up for better accuracy RC clock ON Interrupt LOW on INTn when XY coordinates are ready to be read[1]
Full Power mode	*010x_**y**00x* LP_Pulsed = 0 LP_Active = 1 LP_Continue = 0 INT_act_en = ***y***	<8mA current consumption Continuous read Hall elements in high power permanently RC clock ON Interrupt LOW on INTn when XY coordinates are ready to be read[1] If *INT_act_en = 1*, after reading the XY coordinate, the next sample is stored and won't be updated until the next read of XY with interrupt release. If *INT_act_int_en = 0*, the last converted XY coordinate is read in real time.

1. The interrupt will be released to HIGH by reading the X_res_int or Y_res_int registers, or by switching the device into a different power mode.

7.4.1 Shutdown Mode

LP_Pulsed = 1, LP_Active = 0, LP_Continue = 0, INT_wup_en = 1 → [0x76] = 1001_x00x

This is the default operating mode when powering up the device, giving the lowest power consumption when the whole system is in idle mode.

The analog part of the AS5011 is powered off (sleep mode). It is waked up every 80ms by an internal low power logic, the hall sensors are read and the XY coordinate of the magnet is computed.

If the magnet position is above the threshold limits Xp, Xn, Yp, Yn, an interrupt will be generated on the INTn pin and the device returns to sleep mode waiting for the next wake up after 80ms. As the host microcontroller receives the interrupt, it can read the X and Y positions or configure the AS5011 to Low Power mode (refer to Section 7.4.2) in order to track the magnet position until it returns to its initial position on the center.

INT_n remains LOW until X_int/Y_int have been read, or after a power mode change. The typical coordinates read application after an interrupt is to read X first then Y_int.

7.4.2 Low Power Mode

LP_Pulsed = 1, LP_Active = 1, LP_Continue = 0, INT_act_en = 1 → [0x76] = 110x_100x

The Low Power mode is used to track the magnet coordinates when it has been moved from its initial center position.

The AS5011 is in sleep mode and is waked up every 20ms. As soon as the XY position of the magnet is computed, an interrupt is sent on the INTn pin to the microcontroller indicating that a valid coordinate is available, then the sensor returns to sleep mode waiting for the next wake up after 20ms. INT_n remains LOW until X_int/Y_int have been read, or after a power mode change. The typical coordinates read application after an interrupt is to read X first then Y_int.

This mode generates a higher power consumption than the Shutdown mode because of the faster sampling rate and the higher hall sensor current to provide an optimal accuracy of the coordinates.

When the microcontroller detects that the magnet has returned to the initial center position, it has to configure the AS5011 back to Shutdown mode (refer to Section 7.4.1).

7.4.3 Full Power Mode

*LP_Pulsed = 0, LP_Active = 1, LP_Continue = 0 → [0x76] = 010x_**y**00x*

This mode allows the fastest coordinates reading. The sensor stays at its full capability, and never enters in sleep mode.

The interrupt output goes LOW each time a new X and Y result has been computed and the valid data are ready to be read by the host microcontroller. INT_n remains LOW until X_int/Y_int have been read, or after a power mode change. The typical coordinates read application after an interrupt is to read X first then Y_int.

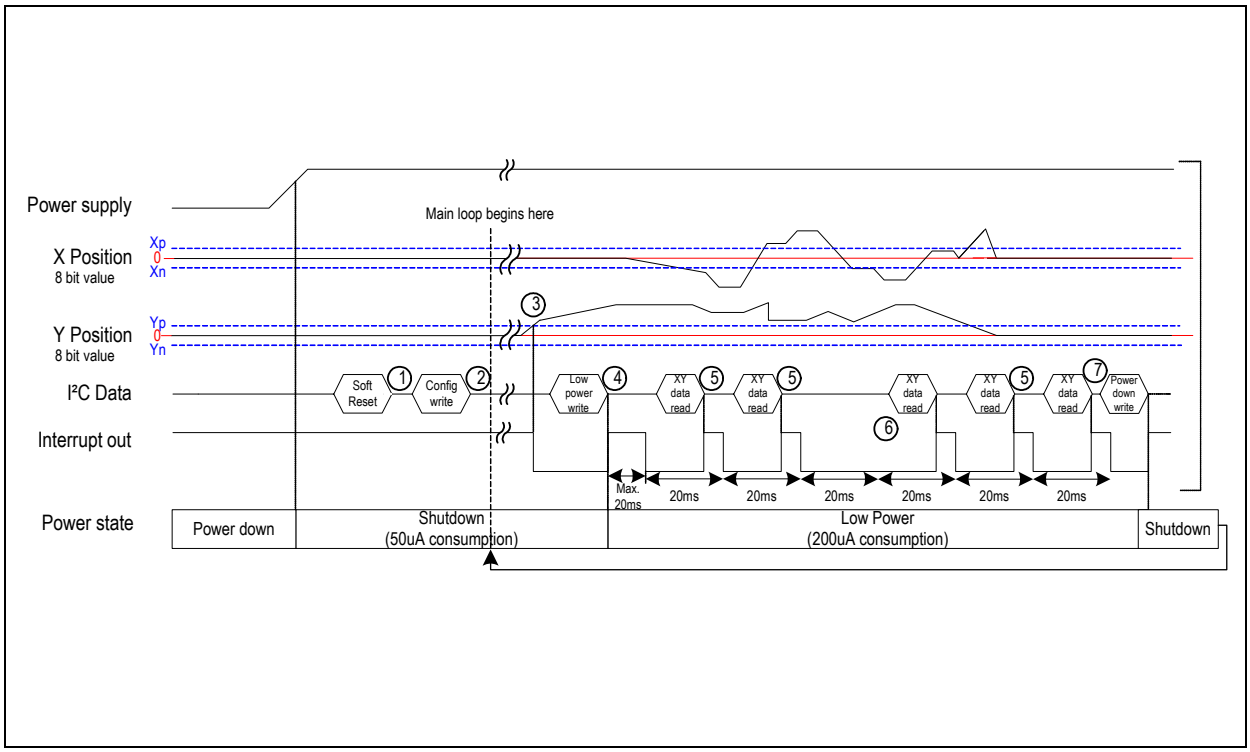
The INT_act_en bit (**y**):

- If *INT_act_en = 1*, after reading the X_int or Y_int register, the next sampled XY coordinate is stored and won't be updated until the next read of X_int or Y_int.
- If *INT_act_en = 0*, the last converted XY coordinate is read in real time.

7.4.4 Switching the Power Modes

The following sequence example would be used for a typical mobile application (mobile phone, PDA, MP3 player):

Figure 10. Typical Application Sequence for Mobile Device



1. After a complete system power up, a soft reset has to be applied by setting bit “soft_rst” in register [0x76]. After soft reset finished, register [0x76] returns to its reset value 98h.
2. Switch to the appropriate power mode by writing the configuration to the AS5011 control registers. Change the inv_spinning bit according to the magnet orientation (refer to Figure 6) or adjust the wakeup threshold levels to the application requirements (refer to Section 8.3).The AS5011 is in shutdown mode per default.
3. The cursor is moved by the user above the Yp threshold. An interrupt is generated and remains LOW until an X_int/Y_int read or a Control Register 1 access.
4. The microcontroller configures the AS5011 in *Low Power mode ([0x76] = 110x_100x)* for faster reading. The interrupt is released to HIGH automatically by the power mode change.
5. Interrupts are generated automatically every 20ms when the XY coordinates are ready for reading.
   The microcontroller reads the X register *[0x41]* then Y_int register *[0x52]* which releases INTn to HIGH. During this phase, the cursor is still moving and stays out of the wakeup thresholds range.
6. If the microcontroller doesn’t read X_int or Y_int immediately after an interrupt, the INTn pin remains LOW until the next read of X_int or Y_int. The last converted (a new sample every 20ms) coordinate will be transferred.
7. The cursor has been released by the user, and returns to the center of the AS5011 (magnet position 1 in Figure 6). The microcontroller will read X,Y = (0,0), and will configure the sensor to *Shutdown mode ([0x76] = 1001_x00x)*.

Note: Firmware application notes with source code example for AS5011 and EasyPoint modules are available on the austriamicrosystems website.

8 Application Information

8.1 2-Wire Serial Interface

The AS5011 communication is done over a 2-wire bi-directional serial interface, similar to I²C protocol for the WRITE mode. The host CPU (master) has to initiate the data transfers, as the AS5011 is a slave device. The 7-bit device address of the AS5011 is '1000 000'.

The SDA signal is bidirectional and is used to read and write the serial data. The SCL signal is the clock generated by the host CPU, to synchronize the SDA data in read and write mode. The maximum 2-WIRE clock frequency is 4MHz in Push-pull configuration. Data are triggered on the rising edge of SCL.

8.2 Interface Operation

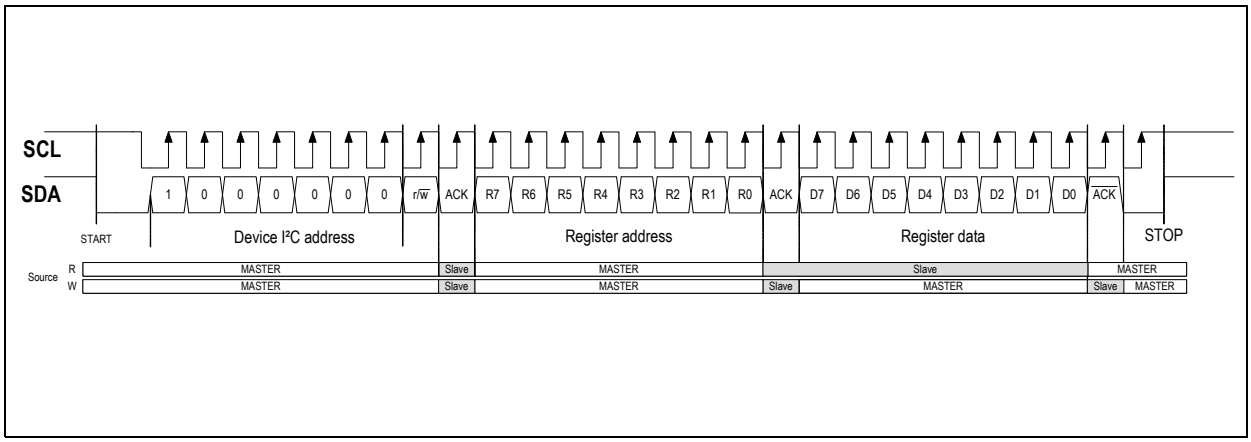
For both read and write data transfers consist of three phases:

1. The master sends a START command by pulling down SDA while SCL remains high. Then the 7-bit device address is sent followed by a read/write bit indicator. In READ mode (r/w = '1'), the slave has to send the data from its selected register. In WRITE mode (r/w = '0'), the master writes the data in the selected register. The slave has to acknowledge by sending '0' after the r/w bit from the master.
2. The slave register is selected by the second data sent by the master. The address has an 8-bit format. The slave has to acknowledge by sending '0' after the bit R0.
3. The 8-bit data is transferred from/to the slave selected register, depending on the r/w bit. At the end of the 8-bit data transfer, the master (read mode) or the slave (write mode) acknowledges by sending '1'. The transfer ends when the master sends a STOP command by sending a low to high transition while SCL remains high.

The AS5011 does not send any acknowledge after the device address or register address (ACK remains High) in the following cases:

- Wrong address
- Write access to a read-only register

Figure 11. 2-Wire Bus Read and Write Operation



8.3 AS5011 Registers

The following registers / functions are accessible over the serial 2-WIRE interface.

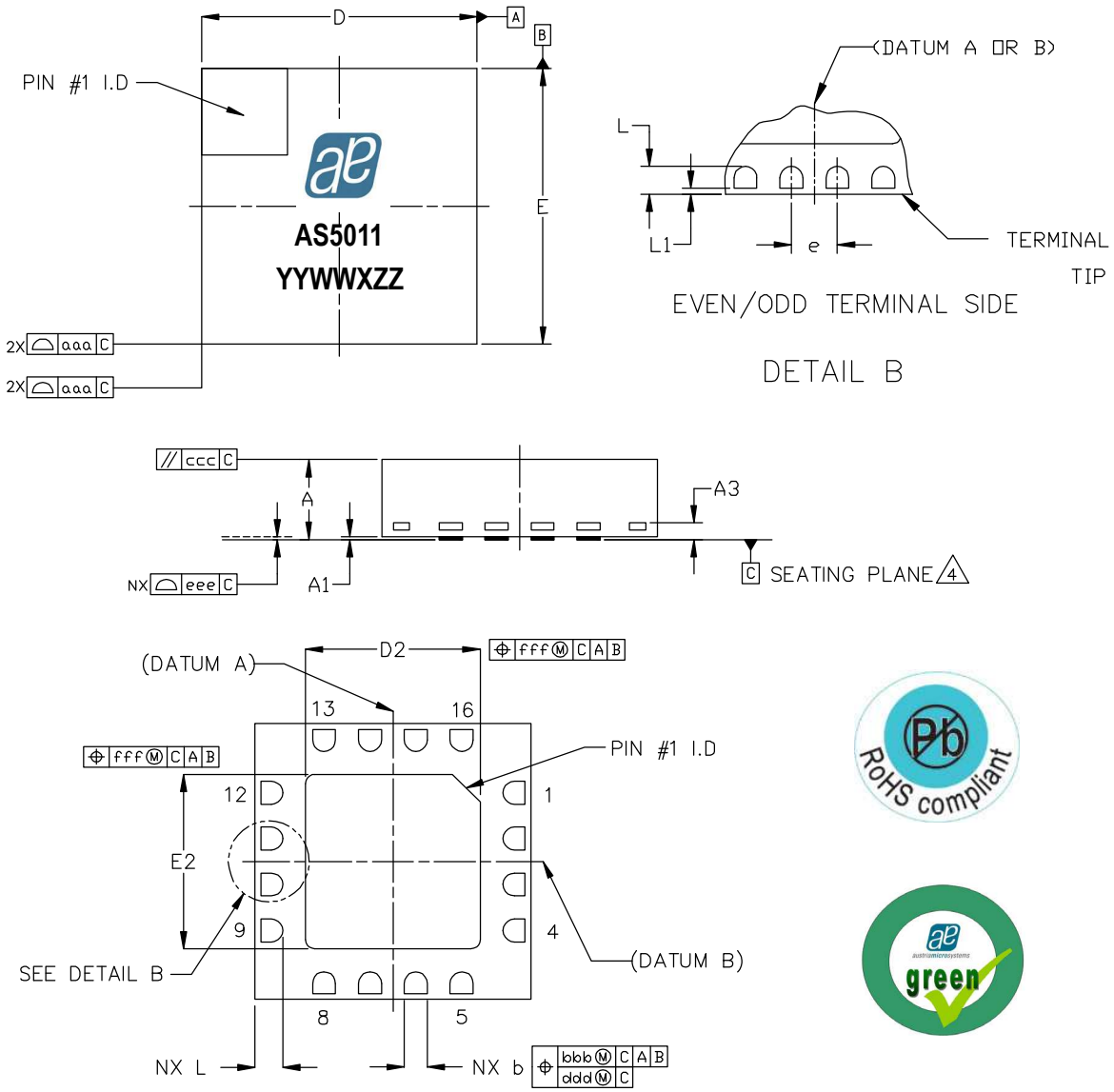
Table 6. AS5011 Registers

Register	Number of bits	Access	Address	Format	Reset Value	Bit	Description
Control Register 1 *(Note: Access to the register resets the interrupt)*							
LP_pulsed	1	R/W	0x76		1	<7>	Low Power control register. See Table 5.
LP_active	1	R/W	0x76		0	<6>	Low Power control register. See Table 5.
LP_continue	1	R/W	0x76		0	<5>	For test only. Must be 0.
INT_wup_en	1	R/W	0x76		1	<4>	Interrupt control register. If set, the interrupt pin goes low in Shutdown mode when the magnet has moved away from the center, above the xp, xn, yp yn threshold values.
INT_act_en	1	R/W	0x76		1	<3>	Interrupt control register. If set, the interrupt pin goes LOW in Low Power mode when a new XY value is ready for reading. Stores coordinate until next read in full power mode,
ext_clk_en	1	R/W	0x76		0	<2>	For test only. Must be 0.
soft_rst	1	R/W	0x76		0	<1>	Soft Reset. soft_rst = 0: normal mode soft_rst = 1: all registers return to their respective reset value
data_valid	1	R	0x76		0	<0>	Data valid. data_valid = 0: no valid XY coordinates data_valid = 1: valid data are ready to be read
Control Register 2							
Test 7	1	R/W	0x75		0	<7>	For test only. Must be 0.
Test 6	1	R/W	0x75		1	<6>	For test only. Must be 1.
Test 5	1	R/W	0x75		0	<5>	For test only. Must be 0.
Test 4	1	R/W	0x75		0	<4>	For test only. Must be 0.
ext_sample_en	1	R/W	0x75		0	<3>	For test only. Must be 0.
rc_bias_on	1	R/W	0x75		0	<2>	For test only. Must be 0.
inv_spinning	1	R/W	0x75		0	<1>	Invert the channel voltage. Set if the magnet polarity is reversed.
pptrim_en	1	R/W	0x75		0	<0>	For test only. Must be 0.
Range and Position Values							
Xp	8	R/W	0x43	two's comp.	0x28 (40d)		Wakeup threshold on the positive X direction.
Xn	8	R/W	0x44	two's comp.	0xD8 (-40d)		Wakeup threshold on the negative X direction.
Yp	8	R/W	0x53	two's comp.	0x28 (40d)		Wakeup threshold on the positive Y direction.
Yn	8	R/W	0x54	two's comp.	0xD8 (-40d)		Wakeup threshold on the negative Y direction.
X	8	R	0x41	two's comp.	0x00		X position. The zero value means the horizontal center position on the AS5011.
Y	8	R	0x42	two's comp.	0x00		Y position. The zero value means the vertical center position on the AS5011.
X_res_int	8	R	0x51	two's comp.	0x00		X position. Releases INT_n to '1'
Y_res_int	8	R	0x52	two's comp.	0x00		Y position. Releases INT_n to '1'

9 Package Drawings and Markings

The device is available in a 16-pin QFN (5x5x0.55mm) and 16-pin QFN (4x4x0.55mm) package.

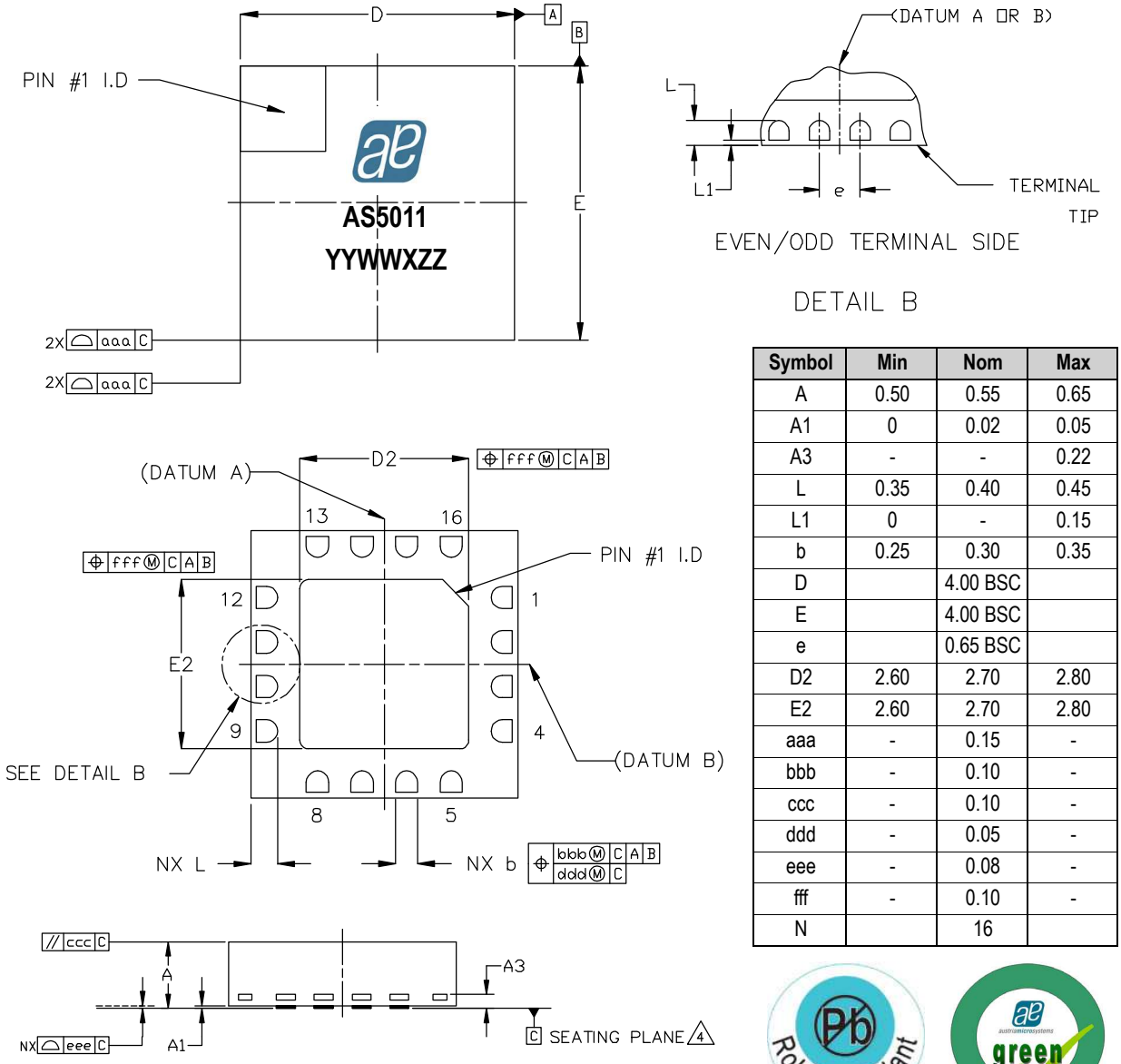
Figure 12. 16-pin QFN (5x5x0.55mm) Package Drawings



Symbol	Min	Nom	Max
A	0.50	0.55	0.60
A1	0	0.02	0.05
A3	-	-	0.22
L	0.35	0.40	0.45
L1	0	-	0.15
b	0.25	0.30	0.35
D	5.00 BSC		
E	5.00 BSC		
e	0.80 BSC		

Symbol	Min	Nom	Max
D2	3.50	3.60	3.70
E2	3.50	3.60	3.70
aaa	-	0.15	-
bbb	-	0.10	-
ccc	-	0.10	-
ddd	-	0.05	-
eee	-	0.08	-
fff	-	0.10	-
N	16		

Figure 13. 16-pin QFN (4x4x0.55mm) Package Drawings



Symbol	Min	Nom	Max
A	0.50	0.55	0.65
A1	0	0.02	0.05
A3	-	-	0.22
L	0.35	0.40	0.45
L1	0	-	0.15
b	0.25	0.30	0.35
D		4.00 BSC	
E		4.00 BSC	
e		0.65 BSC	
D2	2.60	2.70	2.80
E2	2.60	2.70	2.80
aaa	-	0.15	-
bbb	-	0.10	-
ccc	-	0.10	-
ddd	-	0.05	-
eee	-	0.08	-
fff	-	0.10	-
N		16	

Notes:

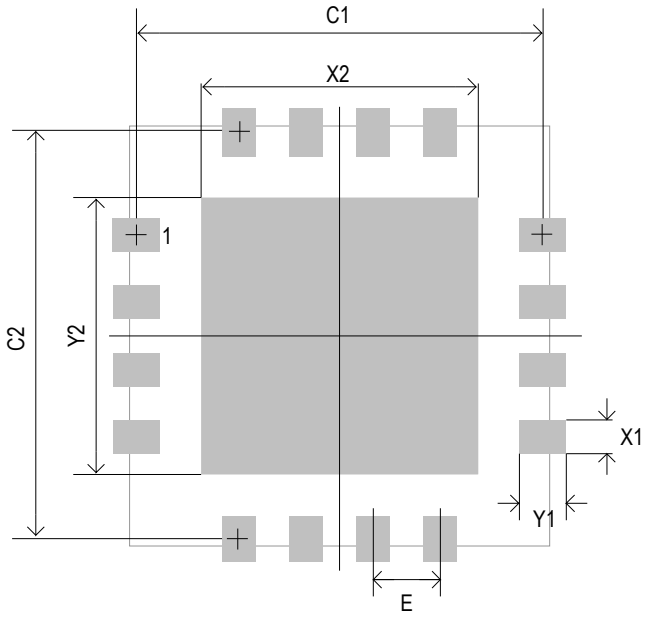
1. Dimensioning and tolerancing conform to *ASME Y14.5M-1994*.
2. All dimensions are in millimeters. Angles are in degrees.
3. Dimension b applies to metallized terminal and is measured between 0.25mm and 0.30mm from terminal tip. Dimension L1 represents terminal full back from package edge up to 0.15mm is acceptable.
4. Coplanarity applies to the exposed heat slug as well as the terminal.
5. Radius on terminal is optional.
6. N is the total number of terminals.

Marking: YYWWXZZ.

YY	WW	X	ZZ
Last two digits of the current year	Manufacturing week	Plant Identifier	Letters for free choice

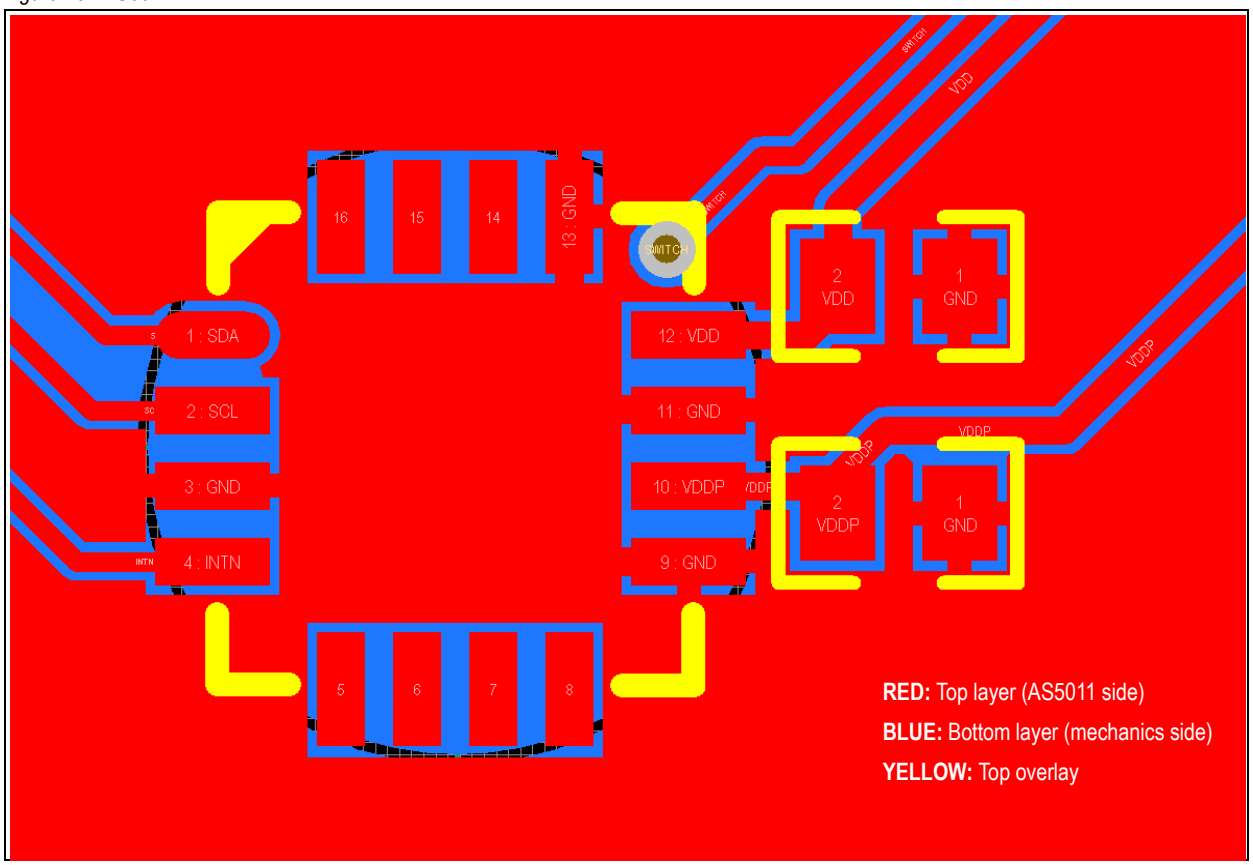
9.1 Recommended Footprint

Figure 14. PCB Footprint QFN-16



Recommended Footprint Data		
Symbol	QFN 5x5 Typ (mm)	QFN 4x4 Typ (mm)
C1	4.8	3.7
C2	4.8	3.7
E	0.8	0.65
X1	0.45	0.40
Y1	0.9	0.7
X2	3.6	2.6
Y2	3.6	2.6

Figure 15. AS5011



Revision History

Revision	Date	Owner	Description
3.05	08 Jun, 2009		QFN 5x5x0.55mm package 2-Wire interface @ 4MHz max.
3.06	03 Jul, 2009		Added AS5000-MA2H-1 Magnet reference
3.10	03 Nov, 2009		Added recommended footprint Added 0x75 register description
3.11	21 Apr, 2010		Added QFN 4x4 Package, footprint and ordering information
3.12	29 Sep, 2011	rph	Updated Table 2 and added Figure 3
3.13	05 Jan, 2012		Updated Figure 4 and Section 7.4.4 Added logos to Package Drawings and Markings on page 15
3.14	24 Jan, 2012		Updated Figure 4 and Package Drawings and Markings on page 15
3.15	15 Feb, 2012		Updated Section 2, Figure 1, Figure 10, Table 3, Table 6 and Section 7.4.4

Note: Typos may not be explicitly mentioned under revision history.

10 Ordering Information

The devices are available as the standard products shown in Table 7.

Table 7. Ordering Information

Ordering Code	Description	Delivery Form	Package
AS5011-IQFT-5x5		Tape & Reel	16-pin QFN (5x5x0.55mm)
AS5011-IQFT-4x4		Tape & Reel	16-pin QFN (4x4x0.55mm)

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