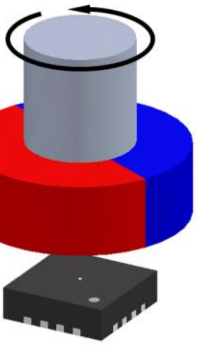
Monolithic Power Systems

MagAlpha MA100

Angular Sensor for 3-Phase Brushless Motor Commutation with Side-Shaft Positioning Capability

Key features

U V W signals for block commutation
Built-in linearization for side-shaft mounting
Adjustable zero
500 kHz refresh rate
Ultra low latency: 3 µs
Serial interface for settings
8.5 mA supply current



QFN-16 3x3mm Package

General Description

The MagAlpha MA100 is a magnetic sensor designed to replace the 3 Hall switches for commutation in 3-phase brushless dc motors. The IC detects the absolute angular position of a permanent magnet, typically a diametrically magnetized cylinder attached to the rotor. The MagAlpha is an extremely fast acquisition and processing sensor, allowing accurate angle measurement at speeds from 0 to 120’000 RPM.

Since the measurement is spatially confined, the user has flexibility in terms of magnet shapes and configurations. This can help relaxing mechanical tolerances and, in case the end of shaft position is not available, the MagAlpha 100 can also operate away from the axis of rotation (“side-shaft” mounting).

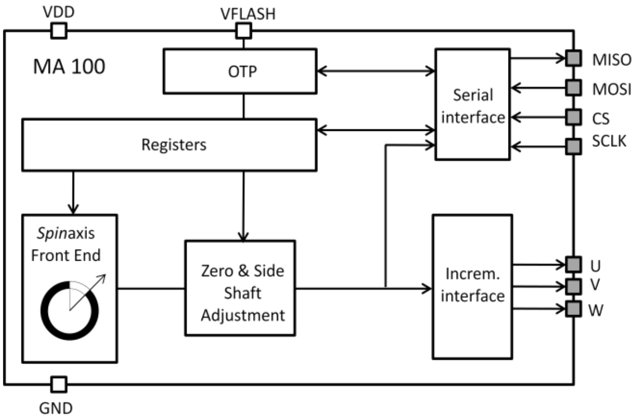


Figure 1: Functional Block Diagram

1. Specifications

TABLE 1 OPERATING CONDITIONS

Parameters	Symbol	Min	Typ	Max	Unit
Supply voltage	VDD	3.0	3.3	3.6	V
Supply current	Isup	6.8	8.5	9.8	mA
Supply voltage for OTP flashing	Vflash	3.6		3.8	V
Supply current for OTP flashing(1)	Iflash	50		100	mA
Operating temperature	Top	-40		125	°C
Applied magnetic field	B	50	80	200	mT

(1) See section 11 for more details about the supply circuit for OTP flashing.

TABLE 2 SENSOR OUTPUT SPECIFICATIONS

Measurement conditions: VDD = 3.3 V, 50 mT < B < 100 mT, Temp = -40 . +125°C, unless otherwise noted

Parameters	Min	Typ	Max	Unit	Remark
Power up time		2	3	ms	
INL	+/- 0.7	+/- 1.5	+/-2.5	deg	
Output drift					
Temperature induced	+/-0.005	+/-0.008	+/-0.05	deg/°C	
Magnetic field induced	-0.005	-0.01	-0.025	deg/mT	
Voltage supply induced	0.0007	0.001	0.005	deg/mV	
Absolute output - serial					
Data output length	8		8	bit	
Refresh rate	500	520	550	kHz	
Latency	2	3	4	µs	
Resolution (3σ noise level)	8		8	bit	
Digital I/O					
Threshold voltage High		1.75		V	
Threshold voltage Low		1.05		V	
Rising edge slew rate		0.7		V/ns	CL = 50 pF
Falling edge slew rate		0.7		V/ns	CL = 50 pF

2. Timing of the Serial Interface

The data link is a 4-wire serial bus, compatible to the Serial Peripheral Interface (SPI) convention shown in Table 3 and Table 4. The MagAlpha sensor operates as a slave. During one transmission a 16-bit word can be simultaneously sent to the sensor (MOSI pin) and received from the sensor (MISO pin).See section 10 “Output Signals” for details.

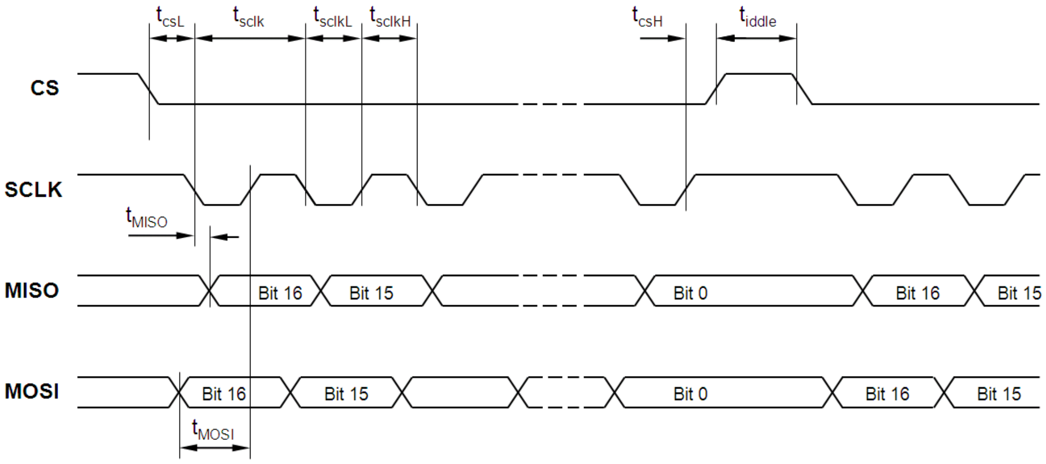


Figure 2: SPI Timing Diagram

TABLE 3 SPI SPECIFICATION

SCLK idle state	High
SCLK readout edge	Rising
CS idle state	High
Data order	MSB first

TABLE 4 SPI STANDARD

CPOL	1
CPHA	1
MODE	3
DORD	0

TABLE 5 SPI TIMING

Parameter	Description	Min	Max	Unit
t_{idle}	Time between two subsequent transmissions	20		ns
t_{csL}	Time between CS falling edge and SCLK falling edge	25		ns
t_{sclk}	SCLK period	40		ns
t_{sclkL}	Low level of SCLK signal	20		ns
t_{sclkH}	High level of SCLK signal	20		ns
t_{csH}	Time between SCLK rising edge and CS rising edge	25		ns
t_{MOSI}	Data input valid to SCLK reading edge	15		ns
t_{MISO}	SCLK setting edge to data output valid		15	ns

3. Registers

TABLE 6 REGISTER MAP

	Register address									
No	**Hex**	**Bin**	**Bit 7 MSB**	**Bit 6**	**Bit 5**	**Bit 4**	**Bit 3**	**Bit 2**	**Bit 1**	**Bit 0 LSB**
3	0x3	0011	BCT(7:0)							
4	0x4	0100	Z(11:4)							
5	0x5	0101	0	0	ETY	ETX	0			
9	0x9	1001	-	-	F5	F4	F3	-	-	-

TABLE 7 PROGRAMMING PARAMETERS

Parameters	Symbol	Number of bit	Brief description	See table
Bias Current Trimming	**BCT**	8	For side-shaft configuration: reduce the Hall device bias current of X- and/or Y-axis	9
Zero setting	**Z**	12	Set the zero position	11
Enable Trimming X	**ETX**	1	When enabled, the X-axis bias current is trimmed by the quantity BCT	10
Enable Trimming Y	**ETY**	1	When enabled, the Y-axis bias current is trimmed by the quantity BCT	10
Flash register *n*	**F*n***	1	Flash the content of register number *n*	

4. Pin Configuration

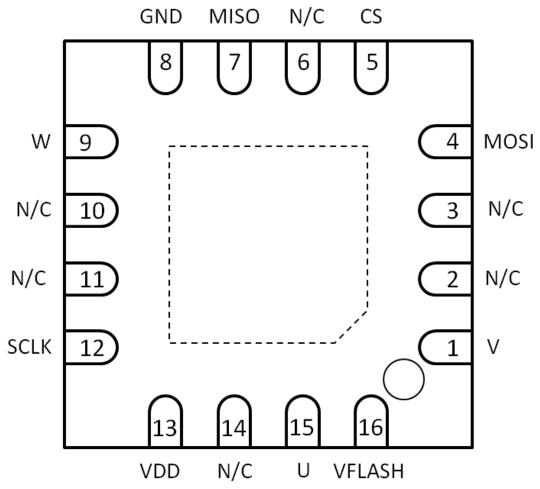


Figure 3: Top view QFN-16

TABLE 8 PIN FUNCTIONS

No	Name	Function
1	V	V (Incremental output)
2	N/C	-
3	N/C	-
4	MOSI	Data in (Serial)
5	CS	Chip Select (Serial)
6	N/C	-
7	MISO	Data out (Serial)
8	GND	Ground
9	W	W (Incremental output)
10	N/C	-
11	N/C	-
12	SCLK	Clock (Serial)
13	VDD	3.3 V supply
14	N/C	-
15	U	U (Incremental output)
16	VFLASH	3.6 V supply for OTP flashing

5. Sensor – Magnet Mounting

The sensitive volume of the MA100 is confined in a region less than 100 µm wide and consists of multiple integrated Hall devices. This volume is located, with a precision of 50 µm in the center of the QFN package, both horizontally and vertically. The sensor detects the angle of the magnetic field projected in a plane parallel to the package upper surface. It means that the only magnetic field that matters is the *in-plane* component (X and Y components) in the package middle point.

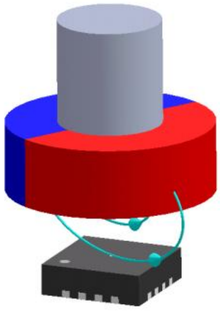


Figure 4: End-of-Shaft Mounting

This detection mode gives flexibility for the design of an angular encoder: all the sensor needs is that the magnetic vector lies essentially within the sensor plane and that its amplitude is comprised between 50 and 200 mT. Note that the MA100 does work with smaller than 50 mT fields, but the linearity and resolution performance may deviate from the specifications (see Table 2). The straightforward solution is to place the MA100 sensor on the rotation axis of a permanent magnet for instance a cylinder diametrically magnetized (see Figure 4).

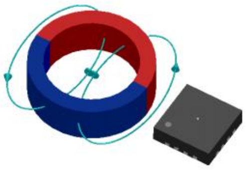


Figure 5: Side-Shaft Mounting

When the end-of-shaft position is not available the sensor can be positioned away from the rotation axis of a cylinder or ring magnet (see Figure 5). In this case the magnetic field angle is not directly proportional to the mechanical angle anymore. The MA100 can be adjusted to compensate this effect and recover the linear relation between the mechanical angle and the sensor output. With multiple pole pairs, the MA100 will indicate multiple rotations for each mechanical turn.

6. Power Supply Decoupling

For most applications, a single 100 nF bypass capacitor placed close to the supply pins sufficiently decouples the MA100 from noise of the power supply. If better decoupling is required, a larger capacitor (10 µF) can be added in parallel with the 100 nF, and/or a resistor (10 Ω) can be added between the supply line and the capacitor node.

In any case, make sure that the connection between the MA100 ground and the power supply ground has low impedance, in order to avoid noise transmitted from the ground. VFLASH needs to be supplied only when flashing the memory. Otherwise the VFLASH pin can remain unconnected or grounded (see Figure 6).

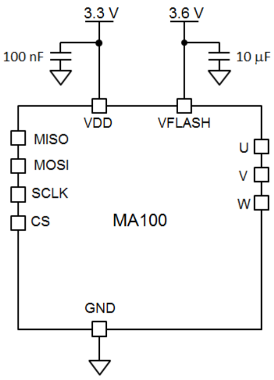


Figure 6: Connection for Supply Decoupling

7. Sensor Front-End

The magnetic field is detected with integrated Hall devices located in the package center. The angle is measured using the *spin*axis method, which directly digitizes the direction of the field without any ATAN computation or any feedback loop based circuit (interpolators, etc.).

The *spin*axis method is based on *phase detection*. It requires a sensitive circuitry generating a sinusoidal signal whose *phase* represents the angle of the magnetic field. The angle is then retrieved by a time-to-digital converter, which counts the time between the zero crossing of the sinusoidal signal and the edge of a constant waveform (see Figure 7). The digitized time is the front-end output.

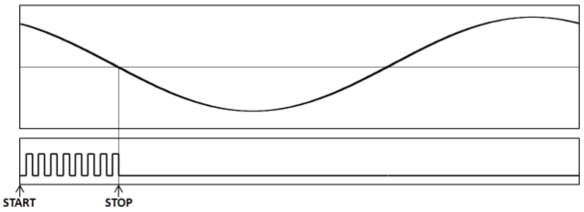


Figure 7: Phase Detection Method. Top: Sine Waveform. Bottom: Clock of Time-to-Digital Converter.

Looking further down the signal conditioning chain, it is crucial that the signal conditioning does not add unwanted phase shifts. For this purpose the MagAlpha incorporates an architecture where these shifts are automatically compensated, resulting in the stability displayed in Table 2. In short, the front-end delivers in a straightforward and open loop manner a digital number proportional to the angle of the magnetic field at the rate of 500 kHz.

Side-shaft

The default current biasing of the Hall devices can be adjusted by programming in order to accommodate low field or compensate non-linearities inherent to side-shaft configurations.

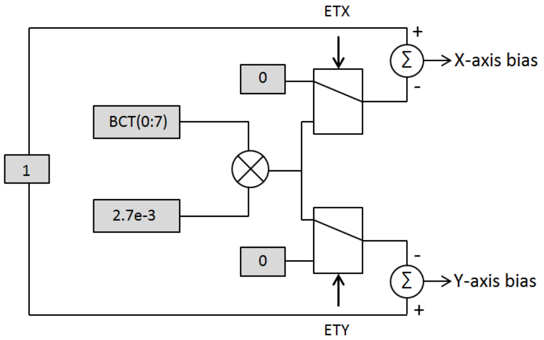


Figure 8: Hall Devices Biasing Diagram

In case the MA100 gets mounted in side-shaft configuration, the relation between the field angle and the mechanical angle is not directly linear anymore. This effect is related to the fact that the tangential magnetic field is usually smaller than the radial field. We define the field ratio k as:

$$k = B_{rad}/B_{tan},$$

where B_{rad} , respectively B_{tan}, is the maximum radial, respectively tangential, magnetic field (see Figure 9).

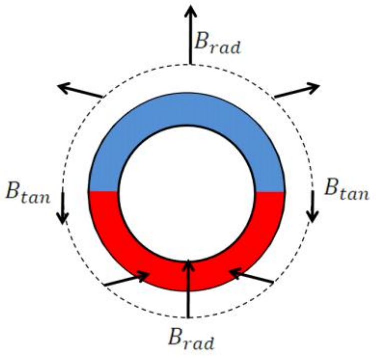


Figure 9: Side-Shaft Field

The ratio k depends on the magnet geometry and the distance to the sensor.

The X-axis or the Y-axis bias current can be reduced in order to recover an equal Hall signal for all angles and therefore suppress the non-linearity. The current reduction is set by the parameter Bias Current

Trimming BCT (7:0), which is an integer from 0 to 255. For an optimum compensation the radial axis should be reduced by the quantity:

$$BCT(7:0) = \frac{255}{0.667}\left(1 - \frac{1}{k}\right)$$

TABLE 9 EXAMPLE OF OPTIMUM BCT SETTING

BCT(7:0)	Magnet ratio k
0	1
1	1.003
…	…
128	1.50
…	…
255	3.00

From the dot printed on the package it is possible to know whether the radial field is detected by the sensor X or Y component (see Figure 10).

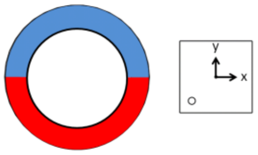


Figure 10: Package Top View with X and Y Axes

First the user must determine which axis needs to be reduced (see the qualitative field distribution around a ring in Figure 9). For instance, with the arrangement depicted in the figure 10, the X-axis should be reduced. Then the parameter ETX or ETY can be set. Note that if both ETX and ETY are set to 1 the current bias will be reduced in both directions the same way, i.e. without side-shaft correction.

TABLE 10 ETX AND ETY

ETX	Enable trimming the X axis
0	Disabled
1	Enabled
ETY	**Enable trimming the Y axis**
0	Disabled
1	Enabled

Zero setting

The zero position of the MagAlpha, α_0, can be programmed with 8 bit of resolution. The angle streamed out, α_{out}, is given by:

$$\alpha_{out} = \alpha_{fe} - \alpha_0,$$

where α_{fe} is the raw angle, out of the front-end. The parameter Z(7:0), which is 0 by default, determines α_0 (table 11). This setting is valid for all output formats: SPI and UVW.

TABLE 11 ZERO POSITION

Z(11:0)	Zero position α_0(deg)
0	0
1	1.41
…	…
255	358.59

8. Programming the MA100

The MA100 incorporates 3 programmable registers. Each register has 8 bit of memory. When the MA100 is powered up, each of these 3 x 8 bit of memory are set to zero, unless the register was previously stored in the One-Time-Programmable (OTP) memory. It means that during startup, the content of the OTP memory is copied to the registers. Once flashed the register content cannot be modified anymore.

In order to set the content of a register, the user must send a digital stream composed of the 4-bit REGISTER WRITE command (0010), followed by a 4-bit register address and the 8-bit value to be sent to the register. The data stream, sent through the MOSI wire, is therefore 16 bits long:

command				reg. address				MSB			value				LSB
0	0	1	0												

Once the command is sent, it will immediately be effective and will affect the next data sent from the MagAlpha.

Read back the register content

It might be helpful to check the content of a register, for instance to verify that the programming was successful. The user must send the REGISTER READ command: 0001, then the 4-bit address of the register under test. The last 8-bit of the stream will be ignored. The user can send for instance 0000 0000:

command				reg. address				MSB			value				LSB
0	0	0	1	x	x	x	x	0	0	0	0	0	0	0	0

The MagAlpha response is *within the same transmission*. In the first byte (simultaneous to the 4-bit READ command and the 4-bit address), the MagAlpha sends the 8 bits of the measured angle A(7:0). The second byte is the content of the register under test. After this transmission the MagAlpha will continue delivering the usual angles A(7:0).

Example

To check the content of the register 4 (0100), which contains the zero setting, send the data:

command				reg. address				MSB			value				LSB
0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0

Simultaneously the MagAlpha replies:

Angle out		MSB value LSB
A(7:4)	A(3:0)	Z(7:0)

9. Output Signals

The raw data coming out of the conditioning blocks is an absolute angle, between 0 and 360 deg. This angle is coded on 16 bits, depending on the value of AF. The absolute output is sent out digitally as serial data. The other outputs, ABZ or UVW, are constructed from the absolute angles.

Absolute - Serial

The bit order of the transmitted data is MSB first, LSB last. The timing requirements are indicated in section 3.

Every 2µs a new data is transferred into the output buffer. The master device connected to the MagAlpha triggers the reading by pulling the CS down. When a falling edge of the CS signal occurs, the data remains in the output buffer until the CS signal returns to logic 1. As the CS is low, the master can read the data by sending clock pulses with a maximum frequency of 25 MHz. There is not any minimum frequency or timeout. See Figure 11 for a simple reading of 8-bit data.

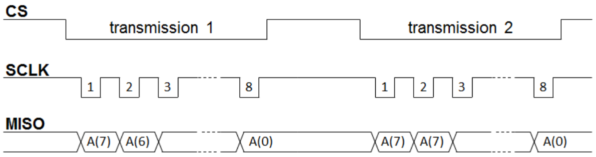
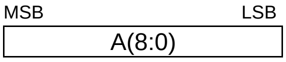


Figure 11: Timing diagram for simple SPI readout

A full reading requires 16 clock pulses. The MA100 delivers:



In case the user needs less resolution, since the MSB is sent first, he can read the angle by sending less than 8 pulses.

If the master triggers the reading faster than the refresh rate the MagAlpha may send several times the same data point.

Block Commutation - UVW

The UVW output emulates the three Hall switches usually used for the block commutation of 3-phases electric motor. The three logic signals have a duty cycle of ½ and are shifted by 60 deg relative to each other (see Figure 12).

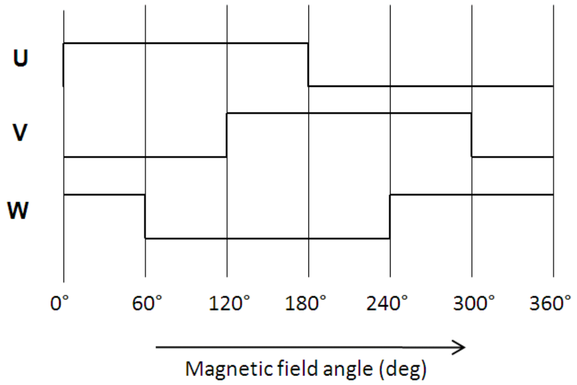


Figure 12: UVW Output during Rotation

10. OTP Programming

The One-Time-Programmable (OTP) memory can permanently store the content of the programmable registers. The OTP memory is made of poly-silicon fuses. By activating the “flash” command the content of the entire register will be stored in the OTP memory. The flash command consists in setting some bits (named F*n*, where *n* is the register number) in the register 9. When the bit F*n* is set, the register *n* is stored permanently. **Important: the user can flash only one register at the time.** It is possible to operate the MagAlpha without flashing the registers.

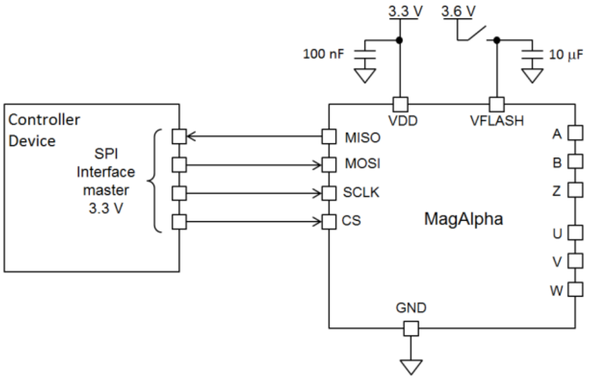


Figure 13: Circuit for Flashing

The burning of the fuses during the flash process is irreversible: once a register is flashed the default values at power up will always be the same. After flashing the registers content cannot be modified anymore (see Figure 13).

Flashing procedure

Prior to flashing, it is recommended to test the MagAlpha with the new settings and verify the performance of the sensor.

Once satisfied, the user can proceed with the flashing:

- Send the parameter to the register, and read back for verification.
- Tie the VFLASH pin to 3.6 V. Note: it is possible to supply both VDD and VFLASH with the same 3.6 V source.
- In the register 9, set the bit corresponding to the register to be flashed.
- Untie the VFLASH pin

Then switch off and on and check by reading back the register content.

Example: set & flash the zero position at 50 deg

Note: permanently storing the zero position requires to burn two registers, the 4 and the 5.

1. Convert into binary: within a resolution of 8 bits, 50 deg is the binary number 00100011 (≈49.22 deg).

2. Store the value (00100011) of the zero position into register 4:

command				reg. address				MSB		value					LSB
0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	1

3. Read back the register 4

command				reg. address				MSB		value					LSB
0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0

If the programming was correct the MagAlpha replies with the register 4 content:

Angle out		MSB		value					LSB
A(7:4)	A(3:0)	0	0	1	0	0	0	1	1

4. Connect the VFLASH pin to 3.6 V

5. Flash register 4:

command				reg. address				MSB		value					LSB
0	0	1	0	1	0	0	1	0	0	0	1	0	0	0	0

6. Disconnect the VFLASH pin from 3.6 V.

7. Turn the MagAlpha off and on, and read back the register 4 to verify that the flashing was successfully accomplished (steps 3).

11. Typical Characteristics

Measurement conditions: VDD = 3.3 V, Temp = 25°C, unless otherwise noted (see Figure 14).

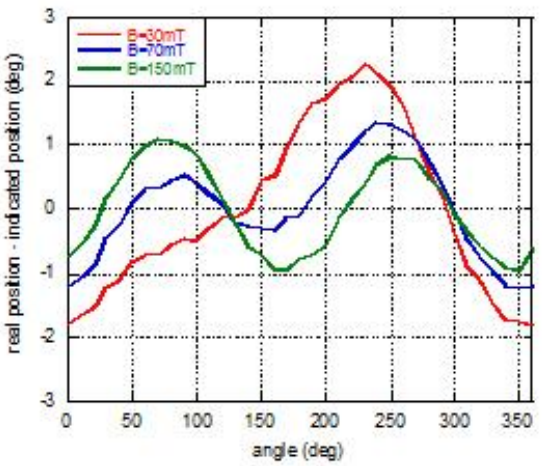
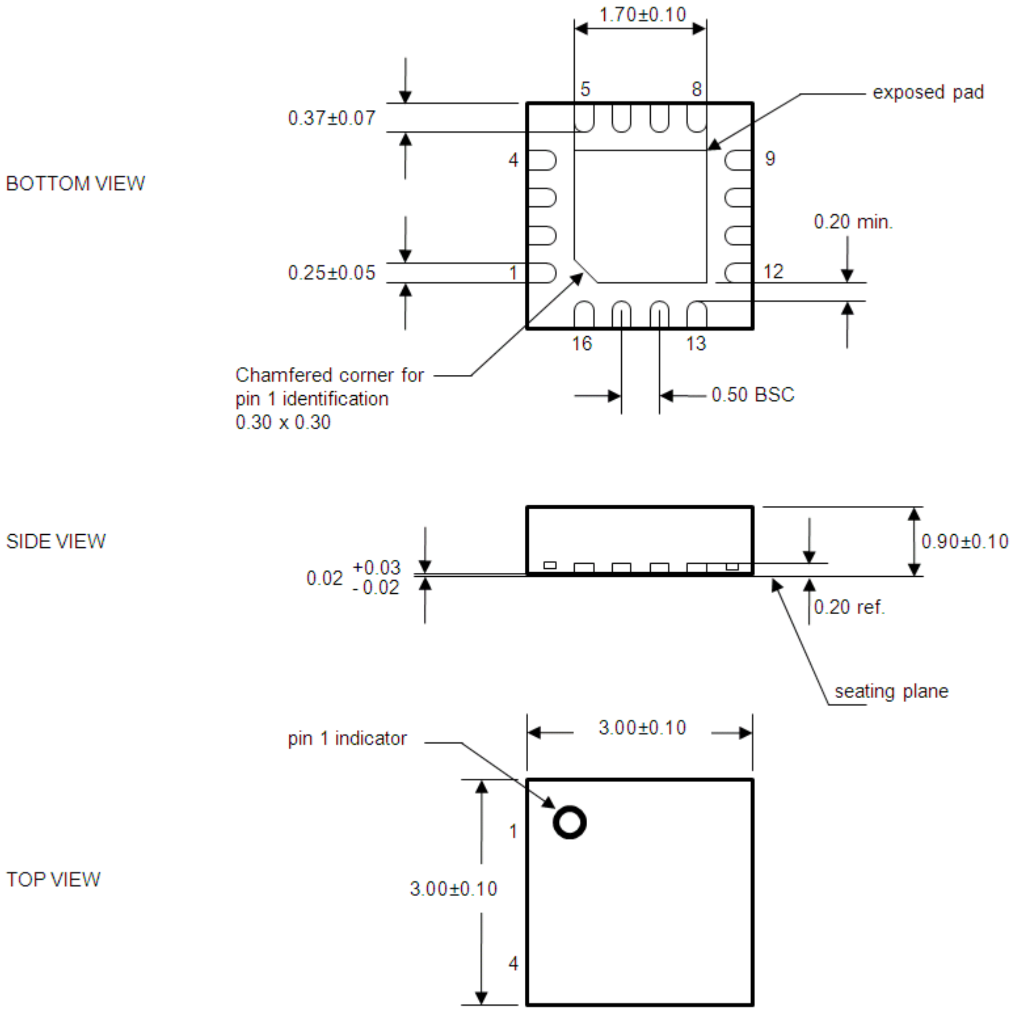


Figure 14: Error Curve at Different Magnetic Fields. The INL is the Maximum Value of this Curve.

12. Package Dimensions

Package: Plastic Quad Flatpack No-lead QFN-16 3x3 mm



NOTES:

1. All dimensions are in mm
2. Package dimensions does not include mold flash, protrusions, burrs or metal smearing
3. Coplanarity shall be 0.08
4. Compliant with JEDEC MO-220

13. Ordering Information

Part Number	Package	Free Air Temperature (T_A)
MA100GQ	**QFN 3x3mm**	**-40° to 125°**

* For Tape & Reel, add suffix –Z (e.g. MA100GQ–Z).

Appendix A: Definitions

Resolution (3σ noise level)	The smallest angle increment distinguishable from the noise. Here the resolution is defined as 3 times σ, the standard deviation in degrees, taken over 1000 data points at a constant position. The resolution in bits is obtained with: $\log_2(360/6\sigma$.
Refresh rate	Rate at which new data points are stored in the output buffer.
Latency	The time between the data ready at the output and the instant at which the shaft passes that position. The lag in degrees is $lag = latency \cdot v$, where v is the angular velocity in deg/s.
Power up time	Starting at power up, time until the sensor delivers valid data.
Integral Non-Linearity (INL)	Maximum deviation between the sensor output and the best line fit.

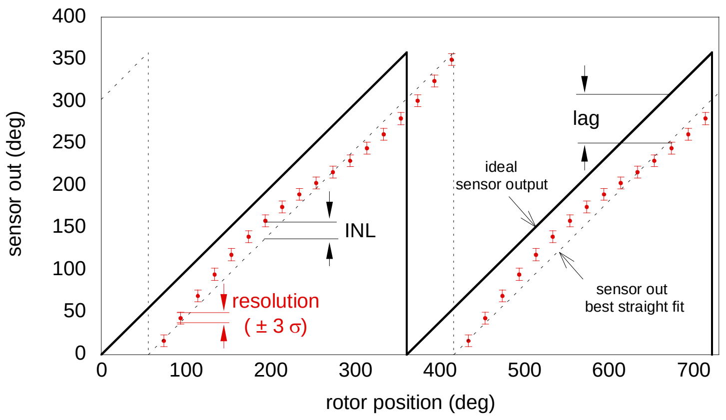


Figure A1: Absolute Angle Errors

Overall reproducibility	Maximum variation between two readings, successive or not, of the same shaft position at a fixed magnetic field over the complete temperature range.

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