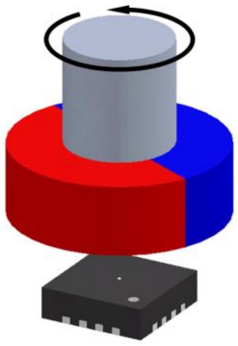
MagAlpha
MA750

Contactless Turning Knob Sensor

Key features

8 bit digital and 12 bit PWM output
500 kHz refresh rate
7.5 mA supply current
Serial interface for data readout and settings



QFN16 3x3mm Package

General Description

The MagAlpha MA750 is a robust contactless angle encoder suitable for control buttons and knobs. The IC detects the absolute angular position of a permanent magnet, typically a diametrically magnetized cylinder attached to the rotor.

The output is digital (SPI) or PWM. For usual potentiometer replacement, the PWM signal can be filtered to obtain an analog signal.

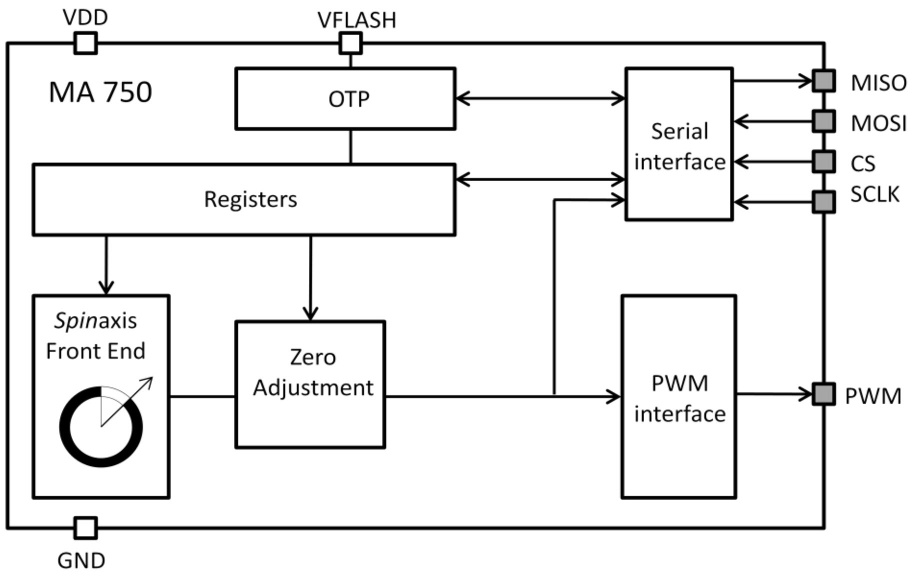


Figure 1: Functional Block Diagram

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	5.7	6.6	8.0	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	30	75	150	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		4	6	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	0.003	deg/mV	
Absolute output - serial					
Data output length	16		16	bit	
Refresh rate	500	520	550	kHz	
Latency	2	3	4	µs	
Resolution (3σ noise level)	8		8	bit	
Absolute output - PWM					
Resolution (3σ noise level)	12		12	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, conmplying to the Serial Peripheral Interface (SPI) usual convention shown in Table 3 and Table 4. The MagAlpha sensor operates as slave. During one transmission a 16 bit word can be simultaneously sent to the sensor (MOSI pin) and received from the sensor (MISO pin). Note that it is possible to receive 24 bits of data (16 bits for the angle and 8 bits for a time index). See section 10 "Output Signals" for details.

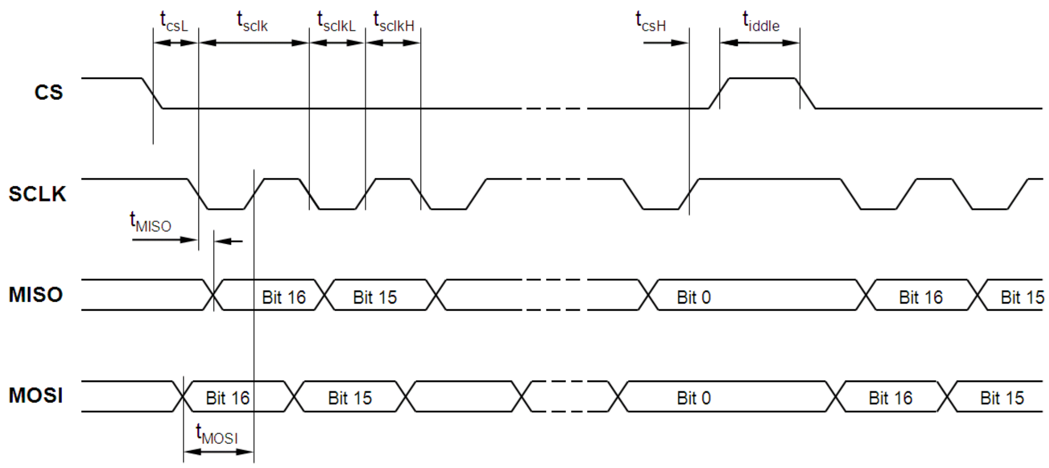


Figure 2: SPI Timing Diagram

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

No	Hex	Bin	Bit 7 MSB	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0 LSB
4	0x4	0100	Z(7:0)							
9	0x9	1001	0	0	0	1	0	0	0	0

(Register address: No, Hex, Bin)

The register 4 contains the zero position and the register 9 is used to flash the register 4.

4. Pin Configuration

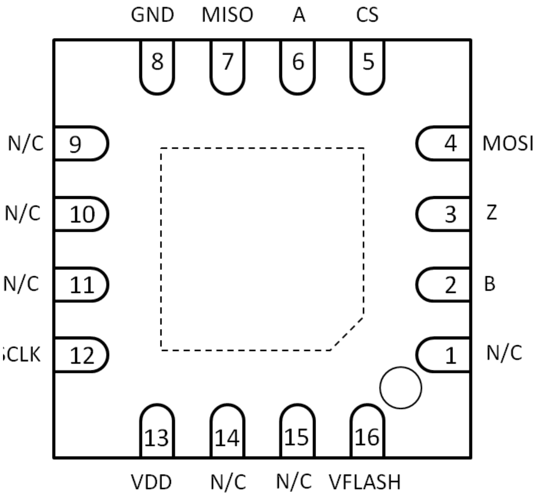


Figure 3: QFN-16 Top View

TABLE 7 PIN FUNCTIONS

No	Name	Function
1	N/C	-
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	N/C	-
10	N/C	-
11	PWM	PWM output
12	SCLK	Clock (serial)
13	VDD	3.3 V supply
14	N/C	-
15	N/C	-
16	VFLASH	3.6 V supply for OTP flashing

5. Sensor – Magnet Mounting

The sensitive volume of the MA750 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.

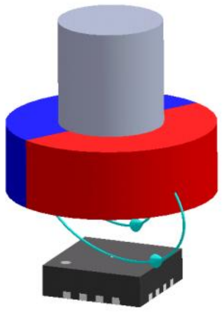


Figure 4: End-of-Shaft Mounting

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 30 and 150 mT. Note that the MA750 does work with smaller than 30 mT fields, but the linearity and resolution performance may deviate from the specifications (see Table 2).

6. Power Supply Decoupling

For most applications, a single 100 nF bypass capacitor placed close to the supply pins sufficiently decouples the MA750 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 (10Ω) can be added between the supply line and the capacitor node.

In any case, make sure that the connection between the MA750 ground and the power supply ground has a 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 5).

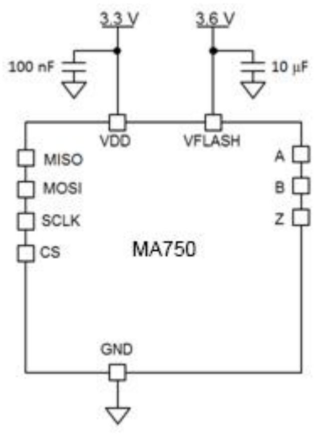


Figure 5: Connection for Supply Decoupling

7. Sensor Front-End

The magnetic field is detected with integrated Hall devices located in the package center. The particularity of this sensor is that 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 6). The digitized time is the front-end output.

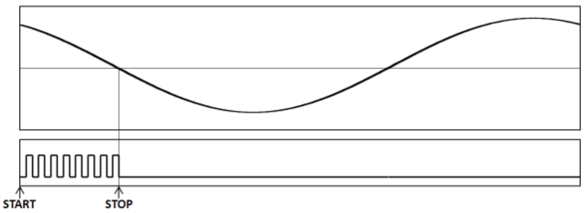


Figure 6: Phase Detection Method. Top: Sine Waveform. Bottom: Clock of Time-to-Digital Converter.

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.

Zero Setting

The zero position of the MagAlpha, α_0, can be programmed with 12 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(11:0), which is 0 by default, determines α_0 (see Table 8). This setting is valid for all output formats: SPI and PWM.

TABLE 8 ZERO POSITION

Z(7:0)	Zero position α_0(deg)
0	0
1	1.41
…	…
255	358.59

8. Programming the MA750

The MA750 incorporates one programmable register with 8 bit of memory to store the zero position setting. When the MA750 is powered up, each of these 8 bit of memory are set to the value 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 the 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	0	1	0	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 the 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	0	1	0	0	0	0	0	0	0	0	0	0

The MagAlpha response is *within the same transmission*.

Simultaneously the MagAlpha replies:

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

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 data.

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 8 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.

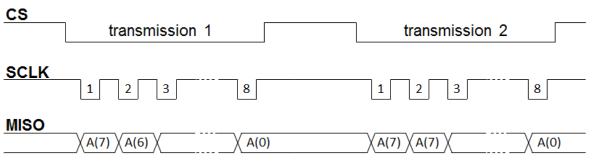
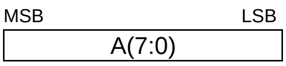


Figure 7: Timing Diagram for Simple SPI Readout

A full reading requires 8 clock pulses. The MA750 delivers:



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

Absolute - PWM

The Pulse Width Modulation (PWM) output must be enabled before use, by setting the parameter PWM. When disabled the PWM pin has large impedance (tri-state logic). This output provides a logic signal whose duty cycle is proportional to the angle of the magnetic field. The PWM frequency is close to 15.3 kHz (the nominal period is 65 µs). The duty cycle is bounded by a minimum value (1/34 of the period) and a maximum value (33/34 of the period). See Figure 8. It means the duty cycle varies from 1/34 to 33/34, with a resolution of 12 bits. The angle can be retrieved by measuring the *on* time. Since the absolute PWM frequency can vary from chip to chip or with temperature, accurate angle detection requires the measurement of the duty cycle, i.e. the measurement both the *on* time t_{ON} and the *off* time t_{off}:

$$\text{angle (in deg)} = \frac{34}{32}\left(\frac{t_{on}}{t_{on}+t_{off}} - \frac{1}{34}\right)360$$

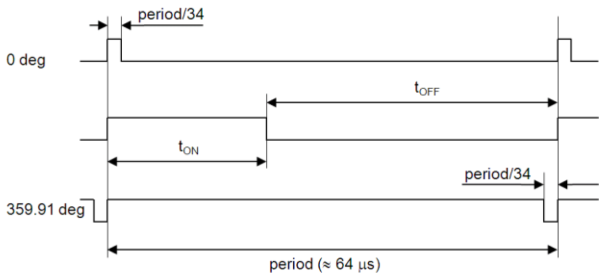


Figure 8: Timing Diagram of the PWM Output

Note: the PWM output can also be used for obtaining a low frequency *analog* output. For this purpose the PWM signal must be low-pass filtered. Caution: the low-pass filter (with time constant τ) will smear the zero angle transition. The transition width will be $\omega \cdot \tau$, where ω is the rotation speed.

An analog signal, emulating a usual potentiometer can be constructed from the PWM output by low-pass filtering. See Figure 9 for a circuit example. The output is a voltage proportional to the angle, radiometric between the supply (VDD) and GND. Note that in tis example the supply must be larger than 3.3 V to correctly supply the MagAlpha. With such as circuit the zero position transition is smeared over ±0.02 deg around zero degree.

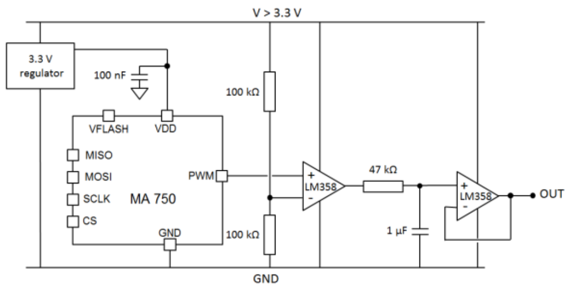


Figure 9: Typical Circuit for Replacement of an Analog Potentiometer

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 in the register 9. When the register 9 is set, the register 4 is stored permanently. It is possible to operate the MagAlpha without flashing the register 4.

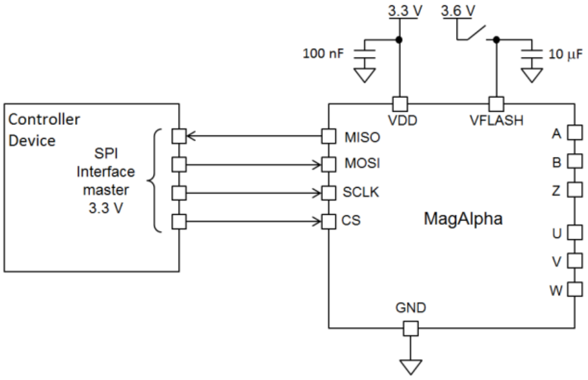


Figure 10: Circuit for Flashing

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.

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.
- Set the register 9 to 0001 0000
- 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

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

2. Store the zero position into register 4:

command				reg. address				value (MSB)							(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				value (MSB)							(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		value (MSB)							(LSB)
A(15:12)	A(11:8)	0	0	1	0	0	0	1	1

4. Connect the VFLASH pin to 3.6 V

5. Flash register 4:

command				reg. address				value (MSB)							(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.

Turn the MagAlpha off and on, and read back the registers 4 and 5 to verify that the flashing was successfully accomplished (steps 3 & 5).

11. Typical Characteristics

Measurement conditions: VDD = 3.3V, Temp = 25°C, unless otherwise noted.

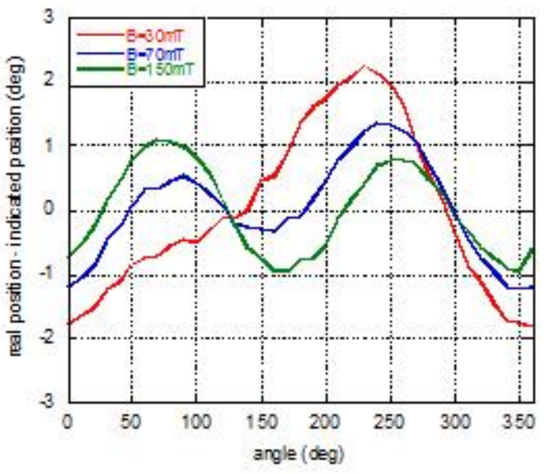
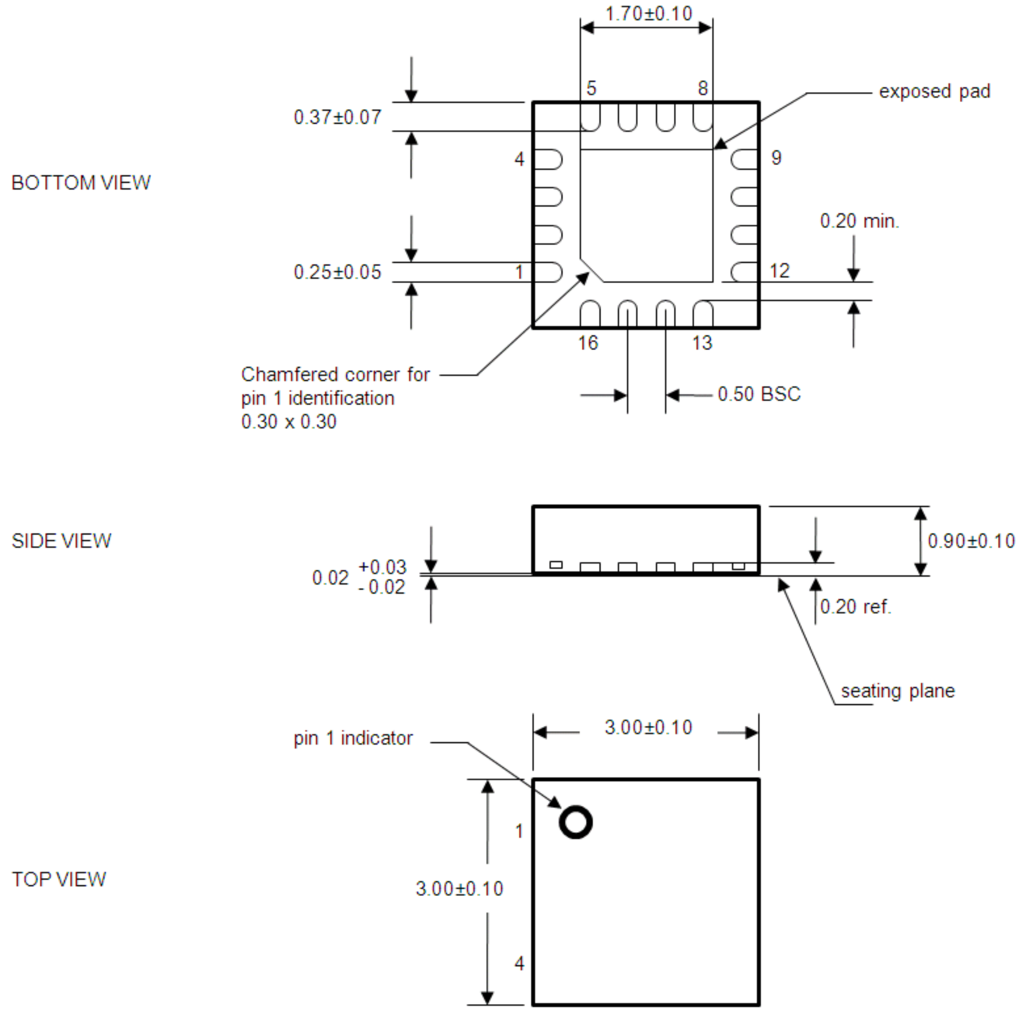


Figure 11: Error Curve at Different Magnetic Fields. The INL is the Maximum Value of this Curve.

12. Package Dimensions

Package: Plastic Quad Flatpack No-lead QFN-16 3x3mm



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)
MA750GQ	QFN 3x3mm	-40° to 125°

* For Tape & Reel, add suffix –Z (e.g. MA750GQ–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.

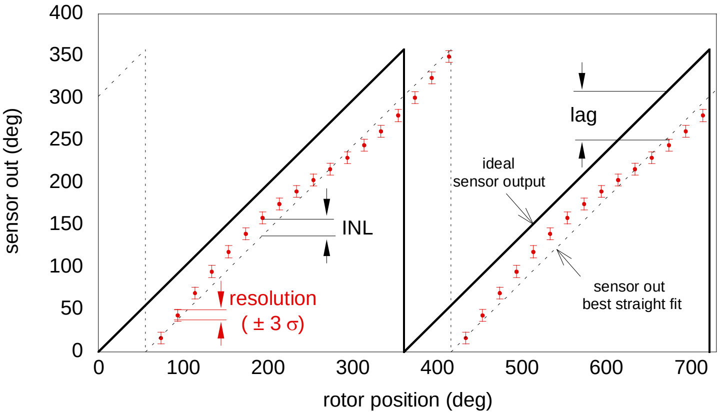


Figure A1: Absolute Angle Errors

Jitter

For the incremental output maximum fluctuation of the angular position of the raising edges.

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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