Monolithic Power Systems

Application Note

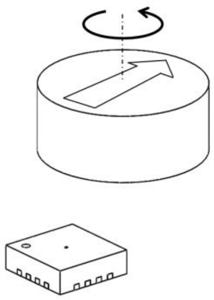
Using the MagAlpha in Off-Axis Mounting

December 2016

Introduction

The MagAlpha is an angle sensor that detects the direction of the magnetic vector locally. Therefore, only the strength and the direction of magnetic field at the sensor position (package center) matters. This leaves some freedom to the user to optimally adapt the magnet-sensor configuration to the application.

Presently, we consider cylinder magnets to be diametrically magnetized.

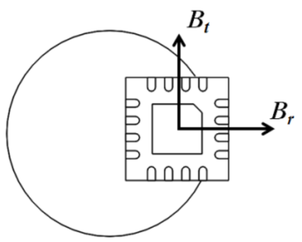


Minimum Field

The MagAlpha can be placed at any position where the in-plane field strength remains above its operational limit (i.e.: 20mT or 60mT, depending on the MagAlpha version). In general, the magnetic field strength varies upon rotating the magnet. Therefore, the smallest field value within one complete turn of the magnet must be considered.

Non-Linearity

If the sensor is placed on the rotation axis, the magnetic field direction is proportional to the mechanical angle. Hence, the output of a sensor is linear in an ideal case. If the position of the sensor is eccentric, it probes a magnetic field out of the rotation axis. In this case, the magnetic field amplitude varies as a function of the angle.

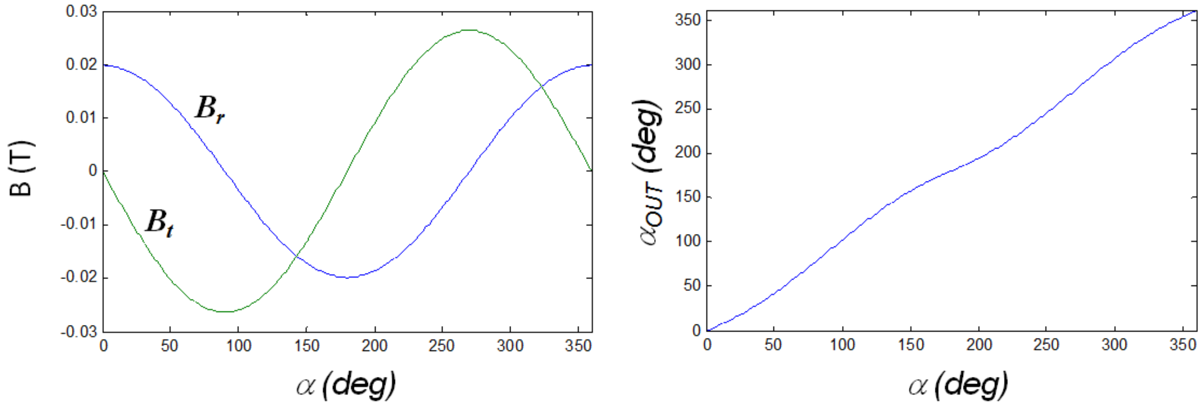


This variation comes along with an angle deviation with respect to a perfectly uniform magnetic field. When decomposing the magnetic field, its radial and tangential components behave as sine and cosine functions with different amplitudes (see Figure 1). This is sometimes called an elliptic error. Consequentially, the angle of the field vector no longer moves proportionally to the mechanical angle. The sensor output is therefore non-linear.

The ellipticity ratio can be defined with Equation (1):

$$k = \frac{B_{r0}}{B_{t0}} \qquad \text{Equ (1)}$$

Where B_{r0} is the radial field amplitude, and B_{t0} is the tangential field amplitude.



Left: Example of Radial and Tangential Magnetic Field Off-Axis
Right: Resulting Non-Linearity
Figure 1

The integral non-linearity (INL) is defined as the maxium deviation from the perfect straight-line response. When k is not too large (up to 2), the INL caused by the ellipticity can be approximated with Equation (2):

$$INL = 45° - a\tan\left(\frac{1}{k}\right) \qquad \text{Equ (2)}$$

The correct relation between the INL and the k ratio, valid also for large k, can be calculated with Equation (3):

$$k = \frac{\tan(INL + \alpha_m)}{\tan(\alpha_m)} \qquad \text{Equ (3)}$$

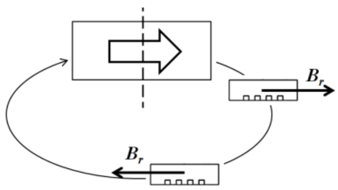
Where a_m is the angular position of the first extremum of the error curve. Table 1 shows k in relation to INL.

Table 1: k vs. INL

k	a_m	INL (deg)	Approximate INL: $45° - \text{atan}\left(\frac{1}{k}\right)$
1.0	45.00	0	0
1.1	46.51	2.72	2.73
1.2	47.63	5.21	5.19
1.3	48.75	7.49	7.43
1.4	50.16	9.59	9.46
1.5	51.08	11.54	11.31
1.6	51.99	13.34	12.99
1.8	53.04	16.60	15.95
2.0	54.73	19.47	18.43
2.2	55.78	22.02	20.56
2.4	57.47	24.31	22.38
2.6	58.38	26.39	23.96
2.8	59.29	28.27	25.35
3.0	60.21	30.00	26.57
3.5	62.03	33.75	29.05
4.0	63.08	36.87	30.96

If this non-linearity exceeds user requirements, the MagAlpha can be configured to compensate for this error. To do this, the trimming parameters BCT, ETX and ETY must be adjusted (see MagAlpha datasheets and the guidelines below).

Direction of Rotation



In the peripheral region (i.e.: where the eccentricity is greater than the magnet radius), the direction of the radial field is reversed with respect to the inner region, while the tangential field is in the same direction (see Figure 2). The result is that the direction of rotation is reversed.

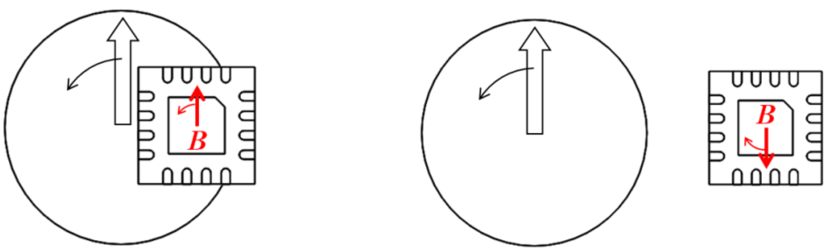
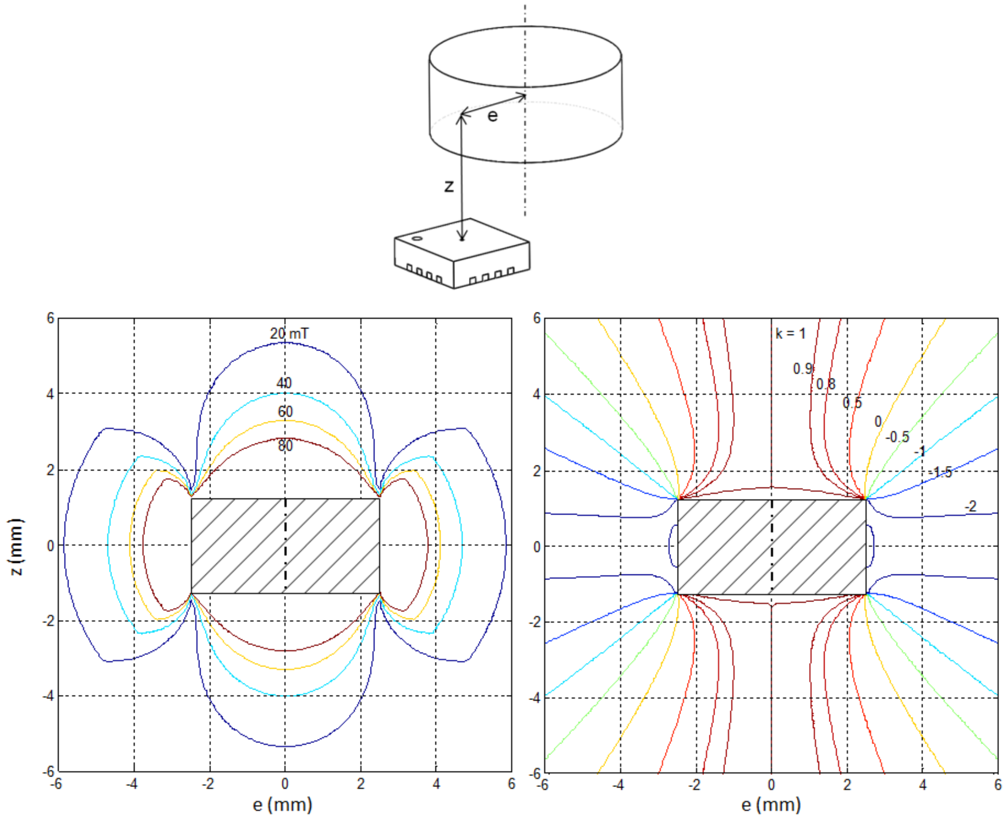


Figure 2: Direction of the Rotating Magnetic Field (Red Arrow) at the Sensor Position Reversed when Eccentricity is Greater than the Magnet Radius

Example

Assume the magnet has a diameter of 5mm, a height of 2.5mm, and a remanent field of 1T.

The sensitive region of the MagAlpha (which is in the package center) can be placed anywhere inside the surface limited by the color lines in the left image in Figure 3. For instance, if the lower limit is 20mT, the sensor must be somewhere within the violet line. The ellipticity is indicated in the right image in Figure 3. Note that the k sign change reflects the change of sign of the radial field and therefore the direction change.

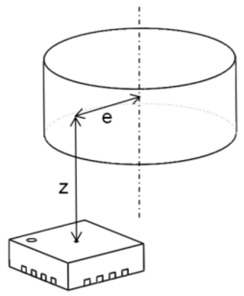


Left: Minimum Field Amplitude Over a Complete Turn
Right: Ellipticity Ratio (i.e.: k ratio)
Figure 3

For instance, if the Magalpha center is positioned at e = 2mm and z = 4mm, the minimum field within one rotation would be 20mT. At this point, the ellipticty ratio is between 0.6 and 0.8. Note that along a curve in the e-z plane (light blue line), the ellipticity is -1. Along this curve, B_{r0} = B_{t0}, meaning that the sensor output is linear without any trimming.

Guidelines for Off-Axis Sensor Positioning

These guidelines are useful for designing a system before having a real setup for testing. Once real measurements can be done, the optimum BCT setting can be obtained directly (see the MagAlpha datasheet).



Whether a certain sensor position is suitable for the MagAlpha and what its optimal setting are can be determined from the values B_{r0} and B_{t0}. These values can be estimated from the graphs in Figure 4. Note that the parameters are normalized by the magnet height: (D/h) for the magnet diameter, (e/h) for the eccentricity, and (z/h) for the sensor vertical position. The field values are given for a remanent field (B_{rem} = 1T). For a different remanent field, multiply B_{r0} and B_{t0} by the ratio B_{rem}/1T.

Once B_{r0} and B_{t0} have been determined, go through the list below.

1. Check that the minimum field (B_{min}) is above the lower limit of the MagAlpha. The minimum field is the lower value between B_{r0} and B_{t0}, calculated with Equation (4):

$$B_{\min} = \min(B_{r0}, B_{t0}) > 20mT \qquad \text{Equ (4)}$$

2. Determine the ellipticity ratio with Equation (5):

$$k = \frac{B_{r0}}{B_{t0}} \qquad \text{Equ (5)}$$

Estimate the INL without correction with Equation (6):

$$INL = \arctan\left(\frac{1}{k}\right) - 45° \qquad \text{Equ (6)}$$

3. If the INL is too large, determine the ellipticity correction using Table 2.

Table 2: Ellipticity Correction

	ETX	ETY	BCT [1]
$k > 1$	1	0	$256\left(1 - \frac{1}{k}\right)$
$k < 1$	0	1	$256(1 - k)$

NOTE:

1) The BCT coefficient is here 256. It may vary in some parts. See the part datasheet for a precise value of the BCT coefficient.

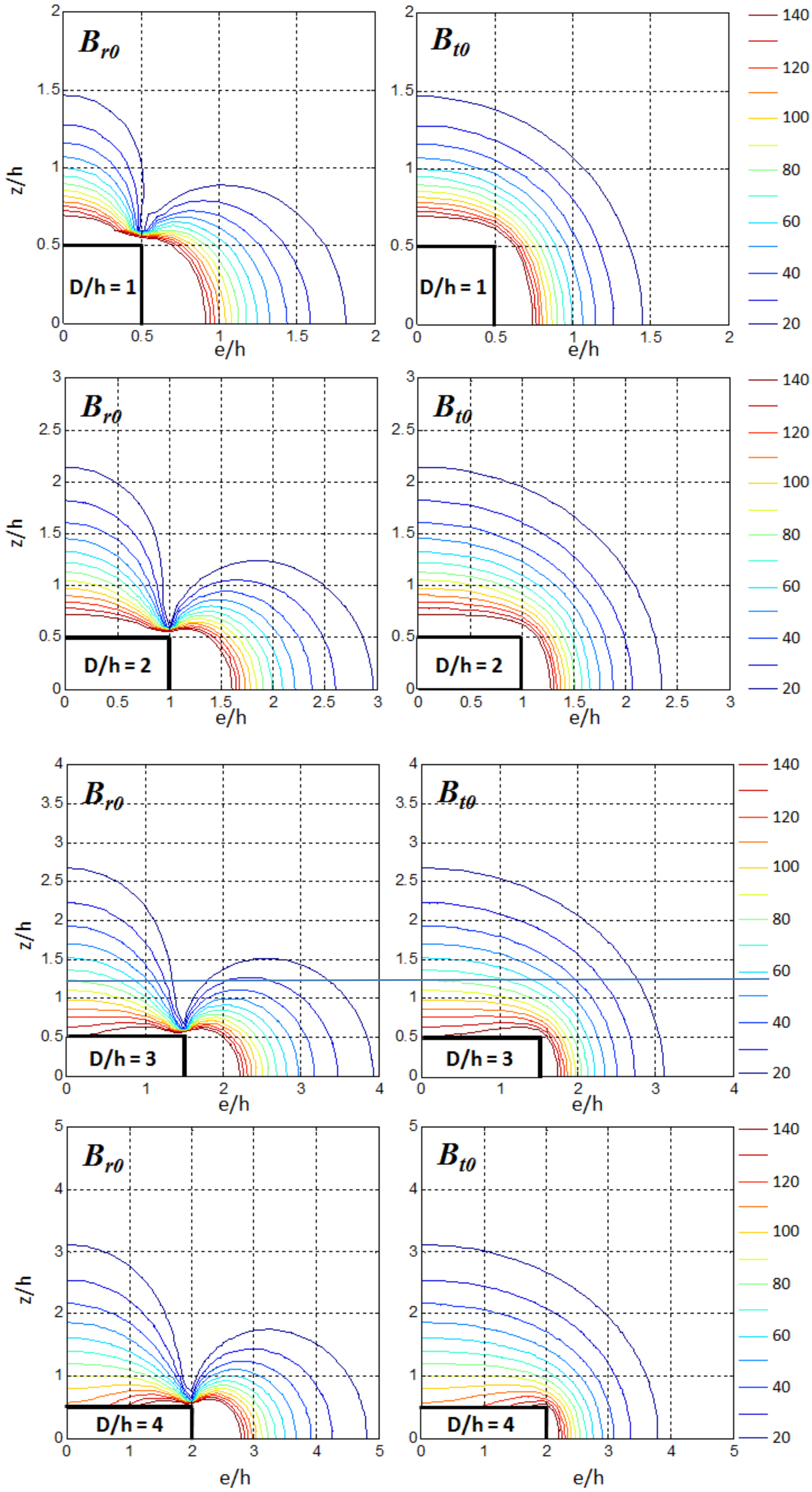
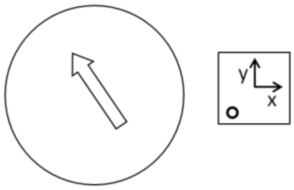


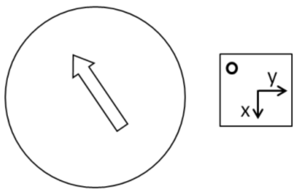
Figure 4: Mapping the Radial and Tangential Fields for a 1T Remanent Field Magnet with Several Aspects

The BTX and BTY settings in Table 2 assumes that the sensor is positioned as displayed below. If rotated by 90°, the ETX - ETY settings are reversed.



Example

Consider the magnet-sensor configuration. The chip is positioned as displayed below (the sensor x-axis is tangential).



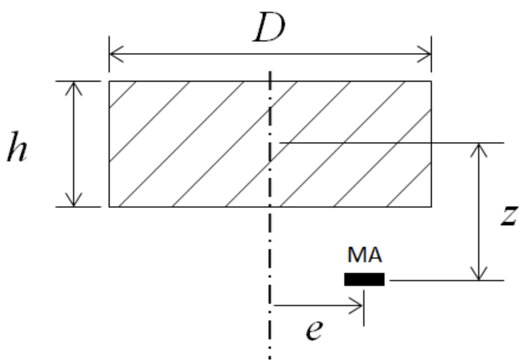


Table 3: Example Magnet Set-Up Parameters

Parameter	Symbol	Value
Diameter (mm)	D	5
Height (mm)	H	2.5
Remanent field (T)	B_{rem}	1.1
Eccentricity (mm)	e	5
Vertical distance (mm)	z	1.25

The normalized coordinates shown in Table 4.

Table 4: Normalized Coordinates

Normalized Parameter	Value
D/h	2
e/h	2
z/h	0.5

The sensor position is shown by the red dots in Figure 5. Table 5 indicates the values extracted from the graph. Note that the normalized values must be multiplied by 1.1 since B_{rem} = 1.1T.

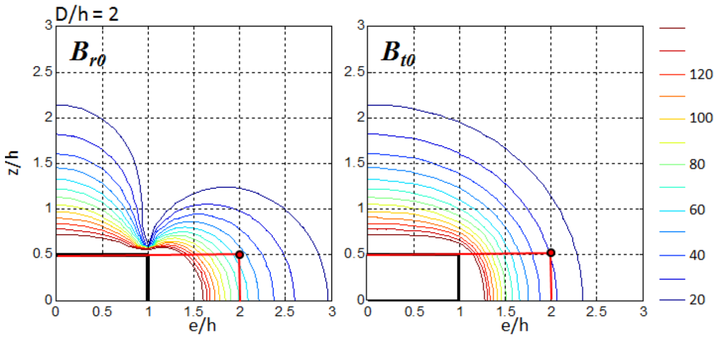


Figure 5: Sensor Position in the Magnetic Field of a Permanent Magnet

Table 5: Radial and Tangential Magnetic Field

		Unit	Radial	Tangent
Normalized magnetic field	B/B_{rem}	-	55	30
Magnetic field	B	mT	60.5	33

Both B_{r0} and B_{t0} are more than 20mT, so the position is fine.

The ellipticity ratio is $k = \frac{B_{r0}}{B_{t0}} = 1.83$. Without trimming, the INL would be 16.3°, as determined by Equation (6):

$$\arctan\left(\frac{1}{1.83}\right) - 45° = -16.3° \quad \text{Equ (7)}$$

To correct the non-linearity, the MagAlpha should be programmed with the equation given in table 2 for k>1:

$$BCT = 256\left(1 - \frac{1}{1.83}\right) = 116 \quad \text{Equ (7)}$$

Since the sensor x axis is tangential and k > 1, the trimming should occur along the Y axis as ETX = 0 and ETY = 1.