Infineon 3D Magnetic Sensor

How to Make a Magnetic Design for Joysticks

3D Magnetic Sensor

Application Note

Rev. 1.0 2016-06-21

Integrated Sensors

Table of Contents

1 Scope

After reading this application note you know how to make the magnetic design for a joystick application with a hall based 3D sensor. Directly, magnet and design parameters are proposed to come quickly to the first running solution. Furthermore, some degrees of freedom or restrictions are presented. Go directly to **Chapter 4.2** to check out the magnetic design proposal.

Note: *The following information is given as a hint for the implementation of our devices only and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device.*

2 Introduction

This application note describes a possible realization of a Joystick Application. With the new product family of the 3D Magnetic Sensor, beginning with TLV493D-A1B6, Infineon offers an innovative solution for three-dimensional magnetic position sensing. By allowing a measurement of all three components of a magnetic field at the same time, it enables a multitude of applications with different ranges. Furthermore the integrated temperature sensor enables the application to compensate possible temperature-dependent magnetic field changes. The family supports automotive requirements as well, e.g. with the TLE493D-W1B6.

Note: *Please also check out the online simulation tool at the Infineon homepage* ***https://design.infineon.com/3dsim/#/****.*

3 Joystick

3.1 Basic principle

A joystick is an input device consisting of a stick that pivots on a base and reports its angle or direction to the device it is controlling. It is also known as the control column and like that mostly used to control video games with multiple buttons. Besides this, joysticks are used for controlling different types of machines in industry, e. g. fork lift trucks.

According to the different purposes of the joysticks, they can be found as analog or digital ones. An analog joystick is a joystick which has a continuous range of positional states, that can be measured as a movement of x and y values. A digital joystick gives only the on-off states of a group of switches, each corresponding to a direction of applied force.

Integrating a 3D sensor inside of the analog joystick, provides more abilities without the need to add any extra mechanics. It detects all movements of the handle in all possible directions. In the next chapter, more details about advantages of this joystick will be described.

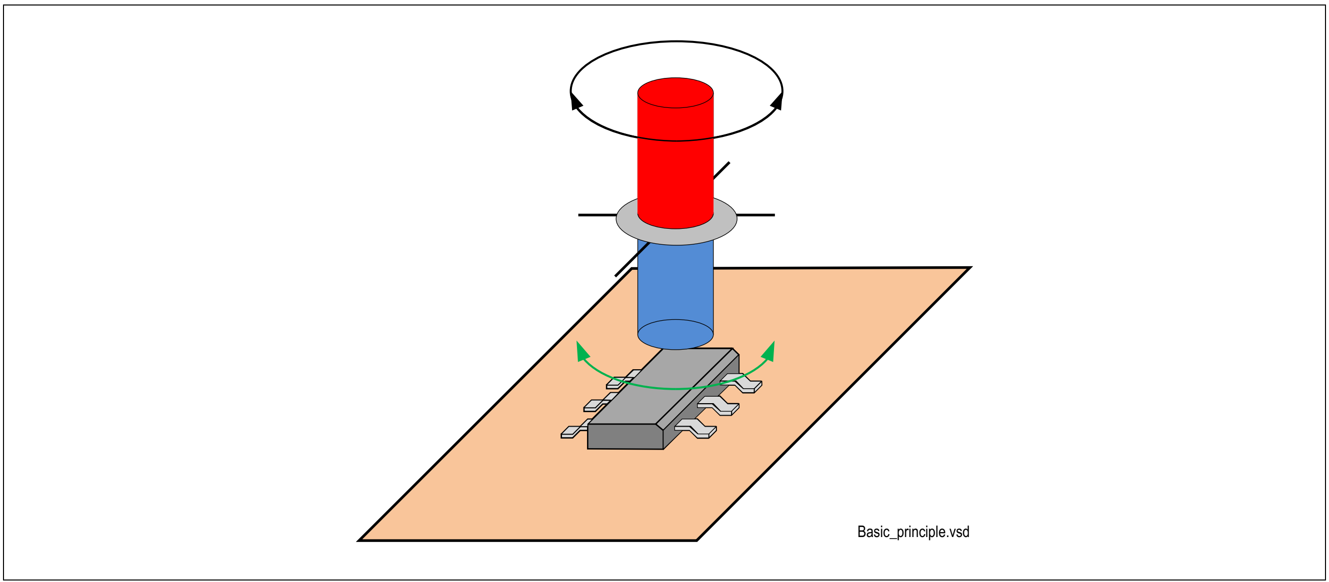


Figure 1 Basic principle of the joystick

A joystick is built out of numerous parts that must be integrated and must match together, in order to implement good results. Depending of desire, joysticks can be built on different ways.

3.1.1 Digital joysticks

Digital joysticks have only four switches for four directions (up, down, left, right). Nevertheless, this type of joystick does not have sensitive control for e. g. racing games.

3.1.2 Analog joysticks

According to this fact, analog joysticks lately replaced digital ones. Analog joystick are more suited for racing games, but need complex mechanics to convert stick movement to 2 axis rotation for potentiometer. An analog design of joystick can be done with two potentiometers, or variable resistors. A potentiometer is there to translate the stick's physical position into an electrical signal. This electrical signal is totally analog. The

potentiometer joystick technology, on the other hand, has limitations in terms of long term durability and reliability. This problem occurs due to the wearing of moving parts.

Some joysticks use an additional potentiometer for a Z-axis, activated by rotating the stick itself. Bringing one more potentiometer in the joystick, makes this system more robust and complicated. New technology with just one 3D sensor implemented can detect all three axis and bring more precise results. With this sensor, lifetime of joystick functionality is extended and more options for future games or industrial implementations of joystick are possible. In the next chapter the new feature of implementing 3D sensor in joystick, without need for potentiometer or more complex system, will be explain in details.

3.2 Joystick with 3D sensor

The hall effect joystick has an advantage versus the potentiometer joystick since it does not have moving parts that will become worn over time. Using a 3D Sensor in analog joysticks brings more advantage than before. One 3D sensor, replaces two or more potentiometers or any extra mechanics. In this case, no separate AD converter is needed. This sensor inside of the joystick features accurate three-dimensional sensing. The magnetic 3D sensor used here, has included temperature sensor as well so it helps with detecting the changes of temperature in a system. Magnetic field detection in x, y, and z direction, allow the sensor to reliably measure three-dimensional, linear and rotation movements.

3.3 Generals in joystick movements

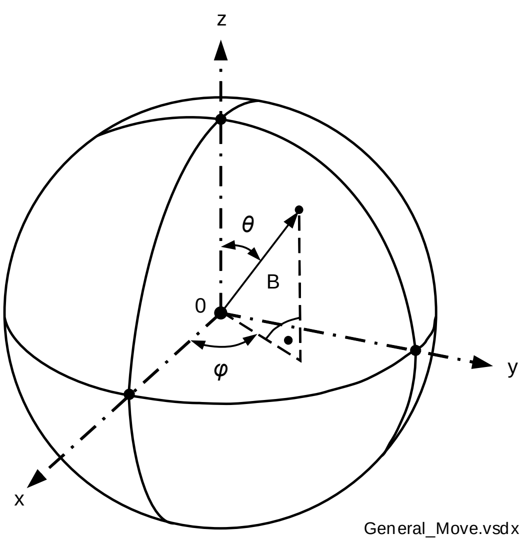


Figure 2 Joystick movements

- In the Zero position (= Z-axis) θ = 0° & φ = 0°
- θ can be between 0° and 180°. φ can be between 0° and < 360° (in-plane of x-y).
- A pure forward or backward movement along the x-axis will lead to an increasing (absolute) Theta θ value. Forward φ = 180°; Backward φ = 0°
- A pure left or right movement along the y-axis will lead to an increasing absolute θ value. (φ will jump from 0° to 90°); Left φ = -90°; Right φ = +90°
- All other movements/positions can be described as a combination of θ & φ

See Appendix in **Chapter 6** for calculations from x-y-z to spherical coordinates.

4 How to design a joystick with a magnetic 3D sensor?

4.1 Definition for joystick applications

First of all, the basic requirements of a joystick shall be noted:

- Mechanical range of movement in x & y direction: α = ±40°
- Accuracy < 5°
- Lifetime = 3 Million cycles
- Current Consumption = < 5 mA

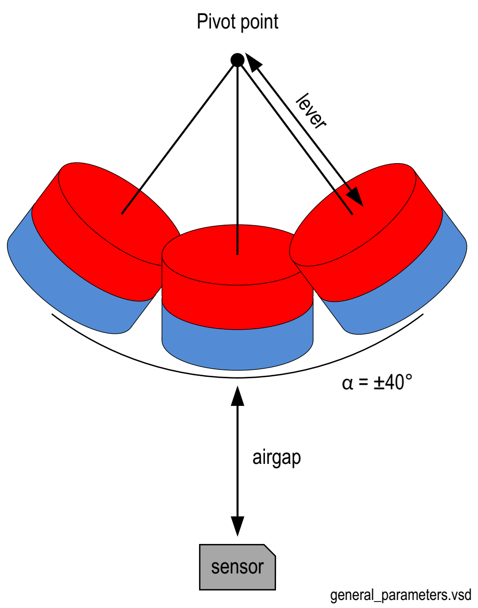


Figure 3 Definition of design parameters (general)

4.2 Magnetic design for standard solution

Option 1 (Standard)

This parameter set offers you a quick and easy solution for your first magnetic design. Further details and design degrees for this option are presented in **Chapter 4.3**.

- Magnet (HF2)
  - B_r = 390 mT
  - Shape = pill magnet
  - Dimensions: Diameter = 8 mm, h= 2mm
  - Material = Hard Ferrite Y30
  - Magnetization Direction = Axial (Z-Direction)
  - Link to magnet supplier: **https://www.magnet-shop.net/ferrit-magnete/scheibenmagnete/scheibenmagnet-8.0-x-2.0-mm-y30-ferrit-haelt-150-g**
- Airgap (Distance Magnet – Sensor) = 4 mm
- Lever Arm (Distance pivot point to magnet) = 4 mm

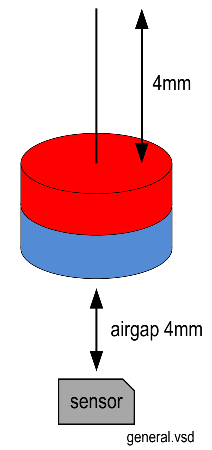


Figure 4 Standard solution (option 1)

Further possible solutions:

Option 2

- Hard ferrite (Y35 ~ HF 30/16)
  - B_r = 410 mT
  - Shape = pill magnet
  - Dimensions: Diameter = 10 mm, h = 5 mm
  - Material = Hard Ferrite Y35
  - Magnetization Direction = Axial (Z-Direction)
  - Link: **www.supermagnete.de/scheibenmagnete-ferrit/scheibenmagnet-durchmesser-10mm-hoehe-5mm-ferrit-y35-unbeschichtet_FE-S-10-05**
- Airgap (Distance Magnet – Sensor) = 4 mm
- Lever Arm (Distance pivot point to magnet) = 4 mm

Option 3 (see Chapter 4.4.2)

This enables a solution with the magnet in the center of rotation.

- NdFeB
  - B_r = 900 mT
  - Shape = cylindrical magnet
  - Dimensions: d = 3mm, h = 8 mm [d = 2 mm simulated]
  - Magnetization Direction = Axial (Z-Direction)
  - Link: **https://www.supermagnete.de/stabmagnete-neodym-rund/stabmagnet-durchmesser-3mm-hoehe-6mm-neodym-n48-vernickelt_S-03-06-N**
- Airgap (Distance Magnet – Sensor) = 6 mm
- Lever Arm (Distance pivot point to magnet) = 0 mm

Note: With block magnets out of the same material a very similar result is assumed compared to the pill or cylindrical shaped magnets.

4.3 Variations of magnet HF2 (Option 1)

In this chapter the dependency on lever and airgap and a change of mechanical dimensions of the magnet are simulated:

Hard ferrite (Y30 magnetization)

Table 1 Parameters

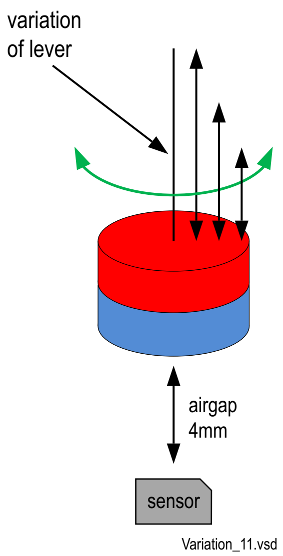
	Standard design parameters	**Variations of parameters**
Magnet	Y30	
B_r	390 mT	
Ø	8 mm	Ø: 8 mm → 6 mm + 10 mm; see **Chapter 4.3.3**
h	2 mm	h: 2 mm → 1 mm + 3 mm; see **Chapter 4.3.4**
Lever	4 mm	Range of lever: 6 .. 10 mm; see **Chapter 4.3.1**
Airgap	4 mm	Range of airgap: 3 .. 8 mm; see **Chapter 4.3.2**
Mechanical angle α	±40°	

Link:
https://www.magnet-shop.net/ferrit-magnete/scheibenmagnete/scheibenmagnet-8.0-x-2.0-mm-y30-ferrit-haelt-150-g

4.3.1 Dependency on lever

In this chapter the dependency on the lever was simulated.

Table 2 Design parameters

Magnet	Y30	
B_r	390 mT	
Ø	8 mm	
h	2 mm	
Lever	**6 .. 10 mm**	
Airgap	4 mm	
Mechanical angle α	±40°	

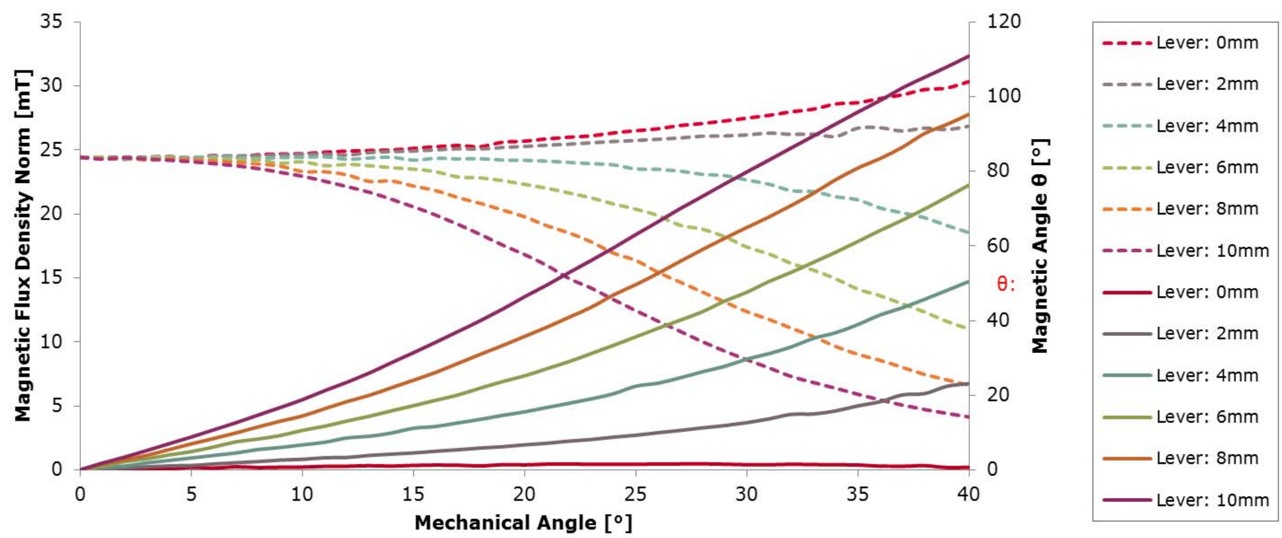


Figure 5 Magnetic flux in spherical coordinates

Conclusion

Table 3

Magnet	**Dimension**	**AG [mm]**	**Lever [mm]**	θ Range	**B-Field**
***B_r* = 390 mT**	Ø = 8 mm	4	0	± 0°	24..30 mT
		4	2	± 23°	24..27 mT
		4	**4**	**± 50°**	**24..19 mT**
		4	**6**	**± 76°**	**24..11 mT**
		4	8	± 95°	24..7 mT
		4	10	± 110°	24..4mT

Findings:

- The bigger the lever, the bigger the available magnetical angle range θ
- The bigger the lever, the smaller is the B-field at mechanical end of movement

Conclusion:

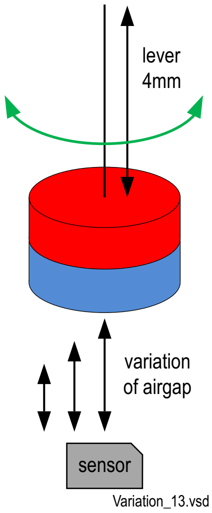
A lever of 4 mm combined with 4 mm airgap is a reasonable approach to have sufficient magnetic field with enough change in magnetic angle θ.

4.3.2 Dependency on airgap

In this chapter the dependency on the airgap was simulated.

Table 4 Design parameters

Magnet	Y30
B_r	390 mT
Ø	8 mm
h	2 mm
Lever	4 mm
Airgap	**3 .. 8 mm**
Mechanical angle α	±40°



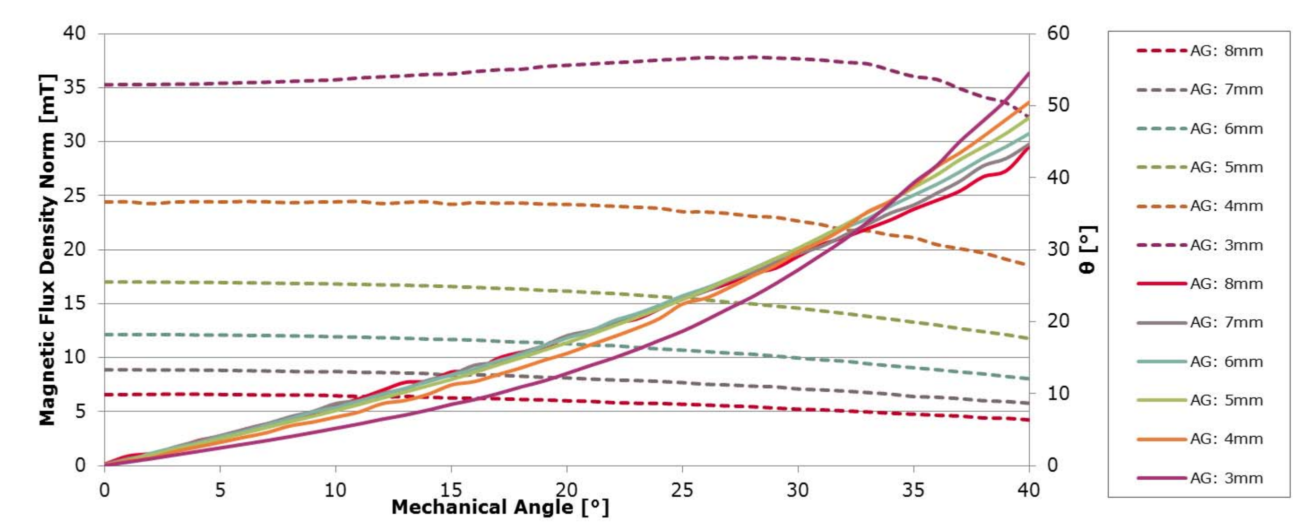


Figure 6 Magnetic flux in spherical coordinates

Conclusion

Table 5

Magnet	**Dimension**	**AG [mm]**	**Lever [mm]**	θ Range	**B-Field**
B_r = 390 mT	Ø = 8 mm h = 2mm	3	4	± 55°	35..33 mT
		4	**4**	**± 50°**	**24..18 mT**
		5	**4**	**± 48°**	**17..11 mT**
		6	4	± 46°	12..8 mT
		7	4	± 45°	9..6 mT
		8	4	± 43°	7..4 mT

Findings:

- The bigger the airgap the smaller the field.
- The bigger the airgap the smaller is the available magnetically angle range θ. But the available range is always sufficient!

Conclusion:

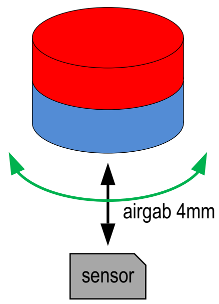
A lever of 4 mm combined with 4 mm airgap is a reasonable approach to have sufficient magnetic field with enough change in magnetic angle θ.

4.3.3 Influence of the pill height of magnet HF2

In this chapter the influence of different magnet dimensions are simulated.
Now the pill height h is modified from nominal value 2 mm to h = 1 mm and h = 3 mm.

Table 6 Parameters

Magnet	Y30
B_r	390 mT
Ø	8 mm
h	**1 mm and 3 mm**
Lever	4 mm
Airgap	4 mm
Mechanical angle α	±40°



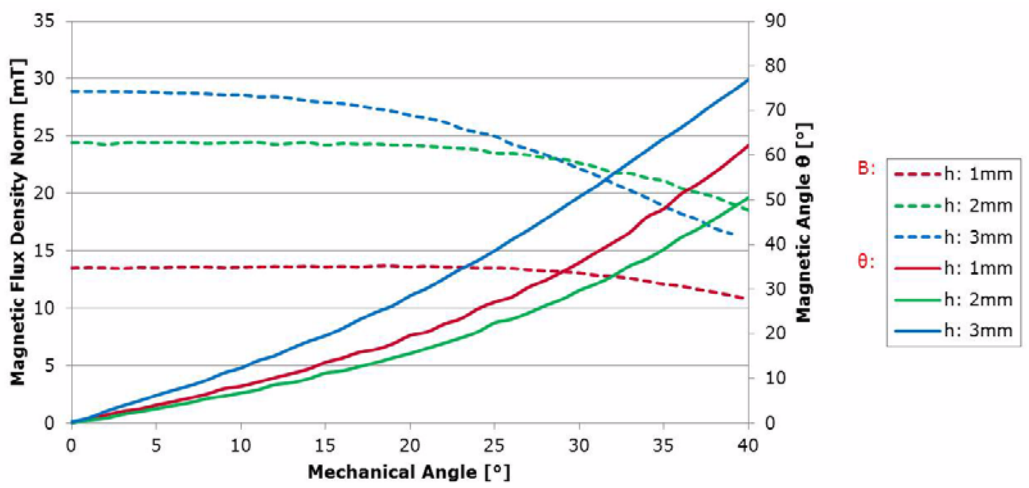


Figure 7 Dependency of pill height

Findings:

- The pill height modulates the available field, the higher the bigger the field.
- The higher the pill the non-magnetic angle is usable.

Conclusion:

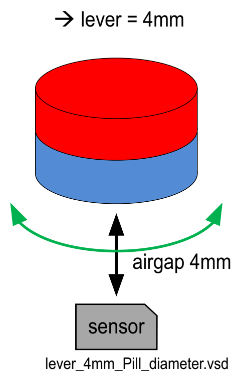
All variations are suitable for a joystick design, even for the thinnest pill.

4.3.4 Influence of the diameter of magnet HF2

In this chapter the influence of the diameter of the magnet is simulated.
The nominal value of d = 8 mm is changed to d = 6 mm and d = 10 mm.

Table 7 Parameters

Magnet	Y30
B_r	390 mT
Ø	**6 mm and 10 mm**
h	2 mm
Lever	4 mm
Airgap	4 mm
Mechanical angle α	±40°



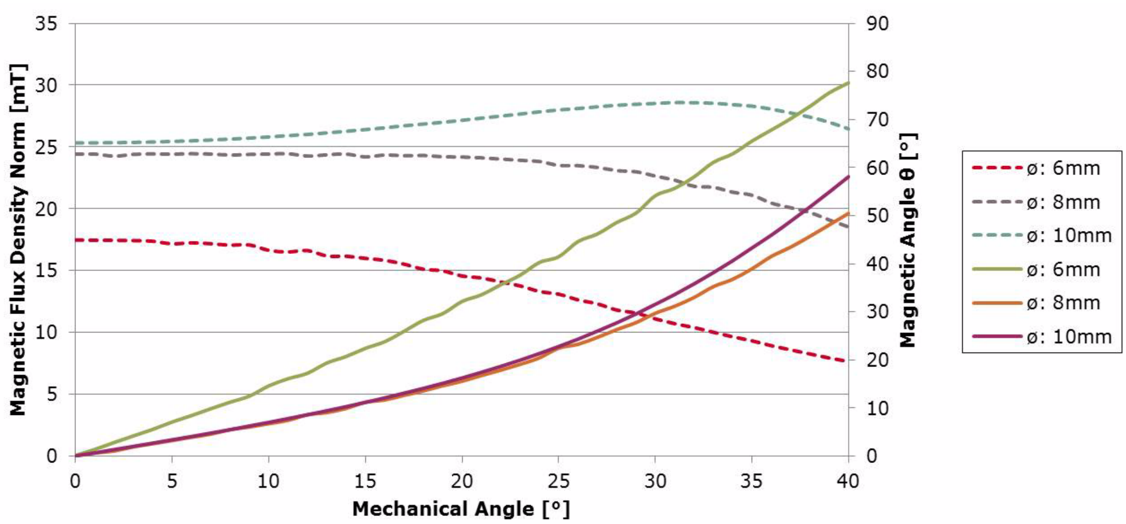


Figure 8 Dependency of diameter

Findings:

- Magnetic field is maybe too small for d = 6 mm (depends on magnetic surroundings).
- Theta is always sufficient.

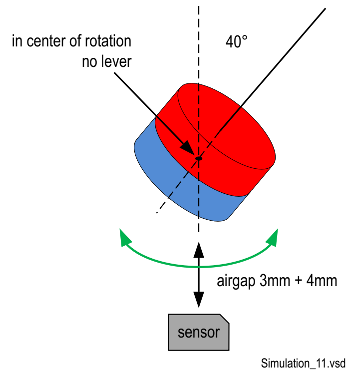
Conclusion:

A joystick design is feasible for sure with d ≥ 8 mm.

4.3.5 Lever = 0 mm

Table 8 Parameters

Magnet	Y30
B_r	390 mT
Ø	8 mm
h	2 mm
Lever	**0 mm; no lever**
Airgap	**3 mm and 4 mm**
Mechanical angle α	±40°



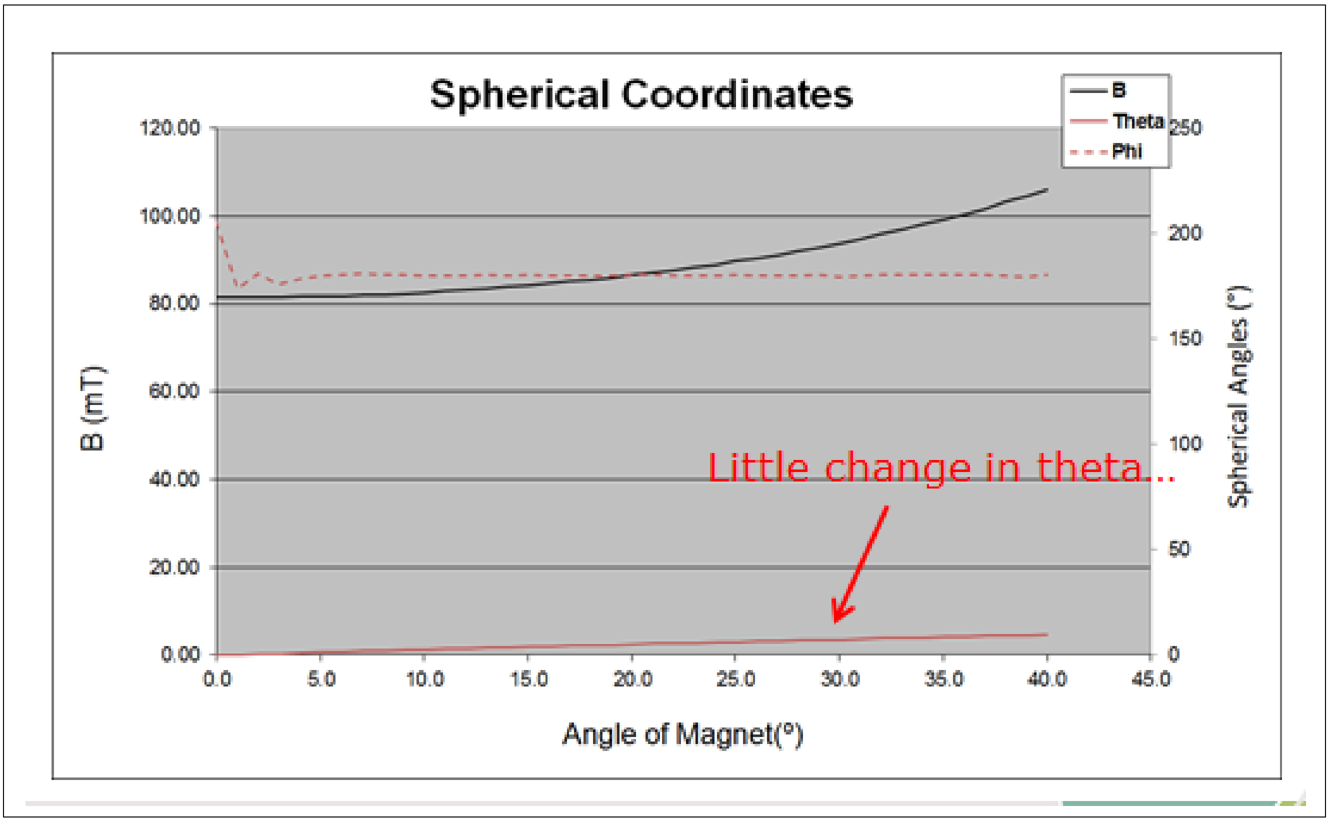


Figure 9 Mag. flux in spherical coordinates @ airgap 3 mm and lever = 0 mm

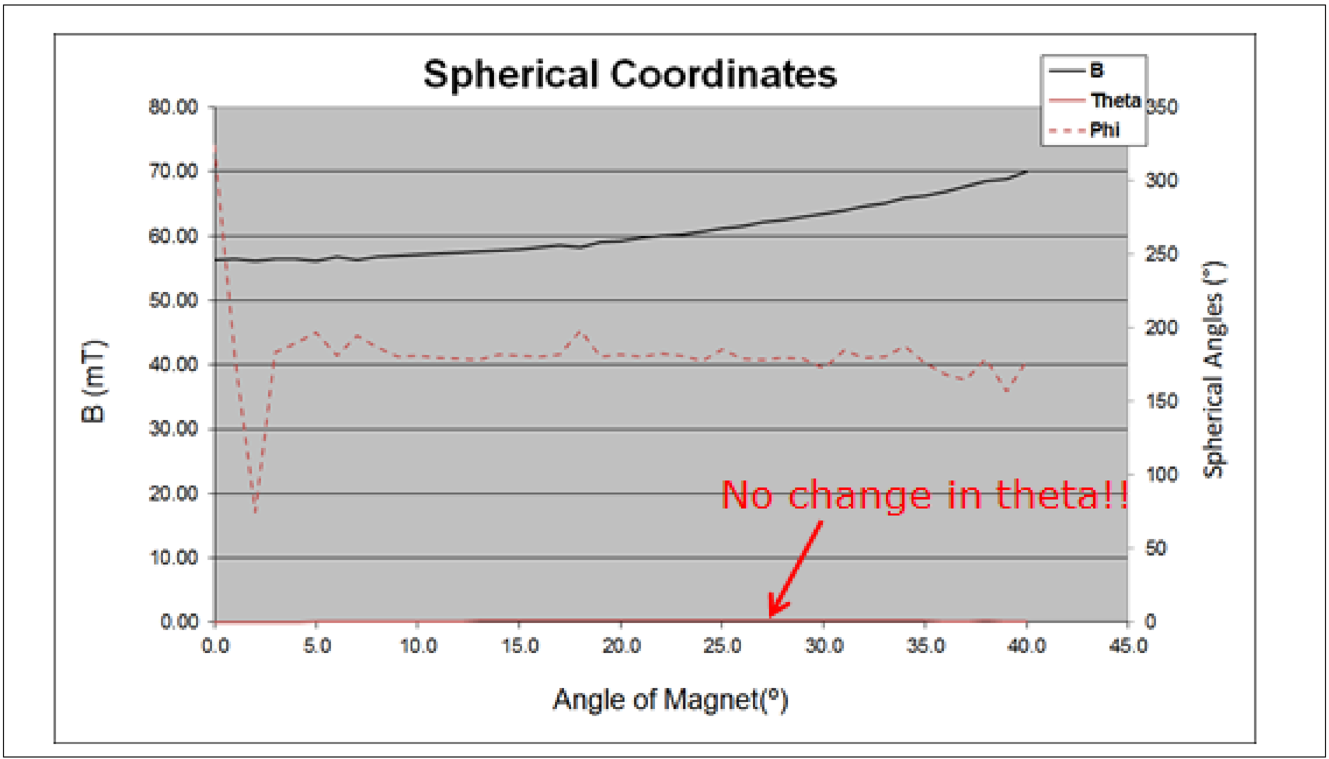


Figure 10 Mag flux in spherical coordinates @ airgap 4 mm

Conclusion:

The angle range theta is very small and not the best solution for a joystick application.

But, out of **Chapter 4.3.4** a reduction of the diameter will increase Theta and may be sufficient for a joystick design.

Furthermore, Chapter 4.4.2 shows the possibility if the magnet needs to be located in the center of rotation!

4.4 Variations of magnet shape

In this chapter more solutions are indicated. Considered are different shapes of magnets.
For further details please check out the dedicated chapter.

Table 9 Summarized key parameters

Magnet	Shape	Dimension	Lever [mm]	AG [mm]	θ Range	B-Field	see
B_r = 900 mT	Pill	d = 8 mm h = 2mm	5	6	± 40°	≥ 30 mT	Chapter 4.4.1.1
			15	6	± 105°	≥ 7 mT	Chapter 4.4.1.2
			15	3	± 138°	≥ 12 mT	Chapter 4.4.1.3
	Cylindrical Option 3	d = 2mm; h = 8 mm	0	3	± 42°	≥ 7 mT	Chapter 4.4.2
	Ball	d = 4 mm	15	3	± 100°	≥ 15 mT	Chapter 4.4.3

General conclusion:

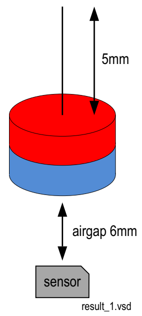
- The bigger the diameter the smaller the change of θ.
- The bigger the lever the higher the range of θ and the smaller the minimum B-field.

4.4.1 Pill magnet: lever and airgap variations

4.4.1.1 Results for lever = 5mm and airgap = 6 mm

Table 10 Parameters

Magnet	Y30
B_r	900 mT
Ø	8 mm
h	2 mm
Lever	**5 mm**
Airgap	**6 mm**
Mechanical angle α	± 40°



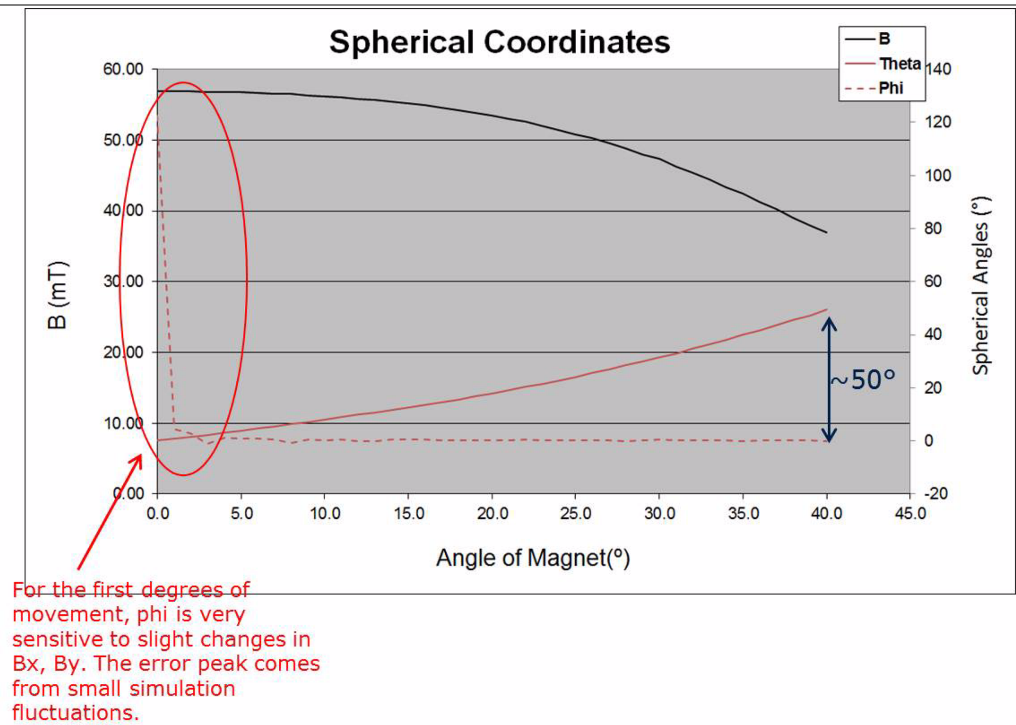


Figure 11 Results

Findings:

- Proportional change of Theta to magnet angle movement
- 40° real movement correspond to 50° change of Theta

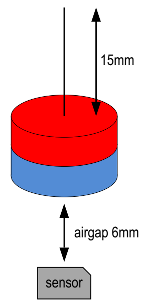
Conclusion:

This parameter set suits well for a joystick application.

At the first degrees of movement, phi is very sensitive to slight changes in Bx, By. The error peak comes from small simulation fluctuations.

4.4.1.2 Result for lever = 15mm and airgap = 6 mm

Table 11 Parameters

Magnet	Y30	
B_r	900 mT	
Ø	8 mm	
h	2 mm	
Lever	**15 mm**	
Airgap	**6 mm**	
Mechanical angle α	± 40°	

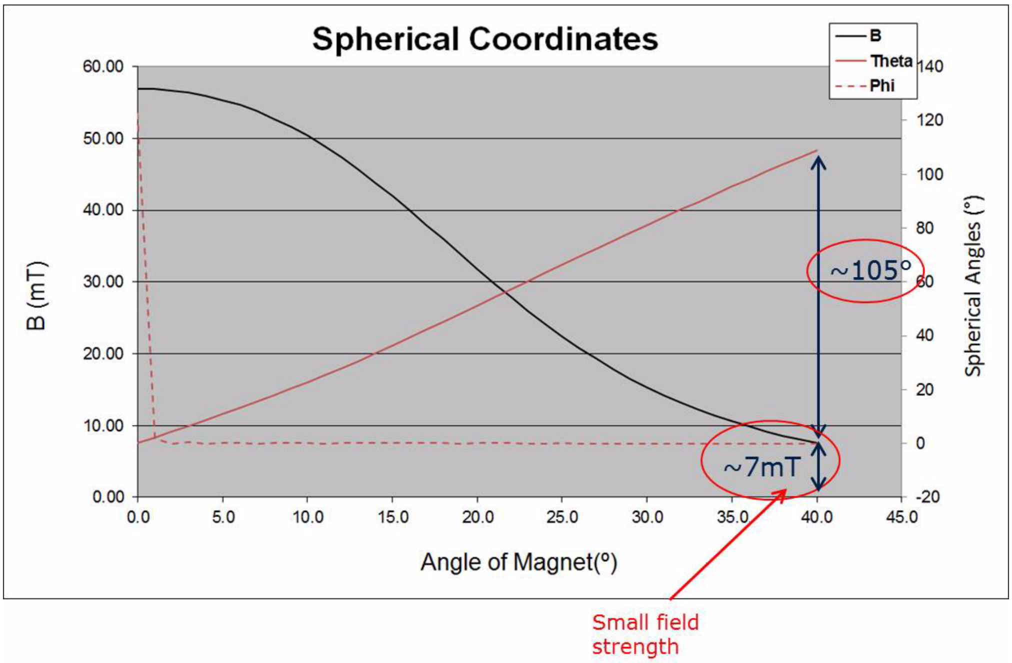


Figure 12 Results for a lever of 15 mm and an airgap (at 0°) of 6 mm in spherical coordinates

Findings:

- Very linear and big range of Theta
- A small field at the end of motion fits only in applications with very little magnetic noise

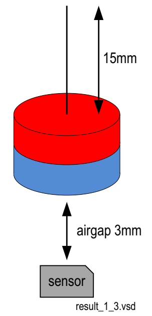
Conclusion:

In order to increase the magnetic field the airgap shall be decreased a bit.

4.4.1.3 Result for lever = 15mm and airgap = 3 mm

Table 12 Parameters

Magnet	NdFeB
B_r	900 mT
Ø	8 mm
h	2 mm
Lever	**15 mm**
Airgap	**3 mm**
Mechanical angle α	± 40°



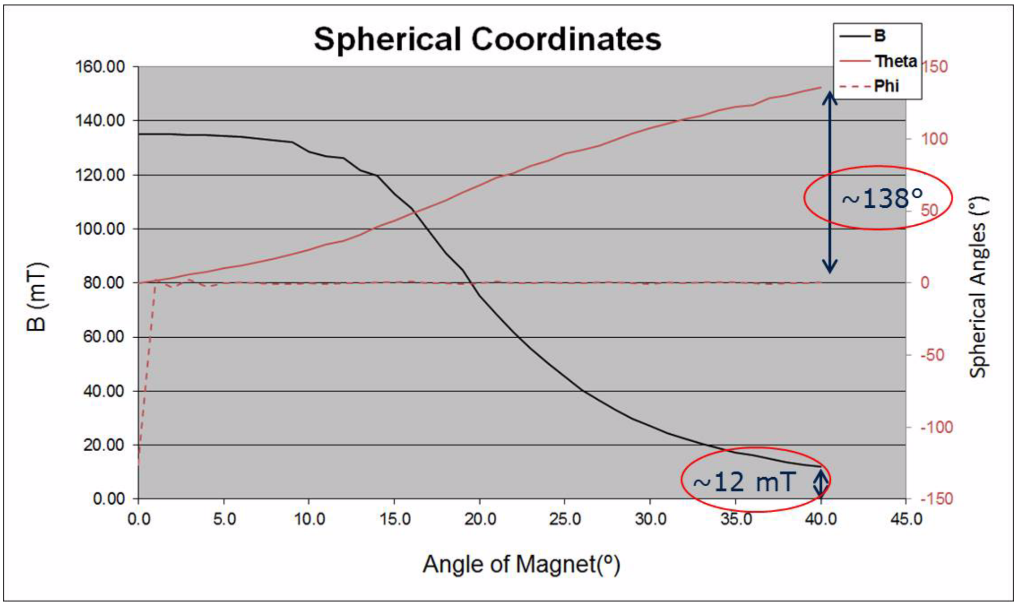


Figure 13 Movement in x-direction; Results for a lever of 15 mm and an airgap (at 0°) of 3 mm in spherical coordinates

Conclusion:

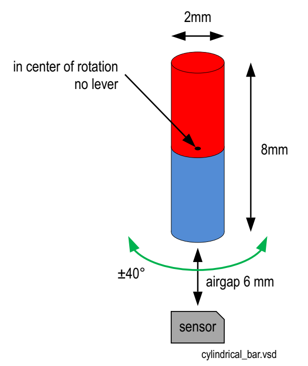
Parameter set fits for joystick application.

4.4.2 Usage of a cylindrical magnet in the center of rotation (airgap 6 mm, no lever (Option 3))

In this second simulation, a very thin, cylindrical magnet is used (B_r = 900 mT)

Table 13 Parameters

Magnet	NdFeB
B_r	900 mT
Ø	2 mm
h	8 mm
Lever	**0 mm**
Airgap	**6 mm**
Mechanical angle α	± 40°



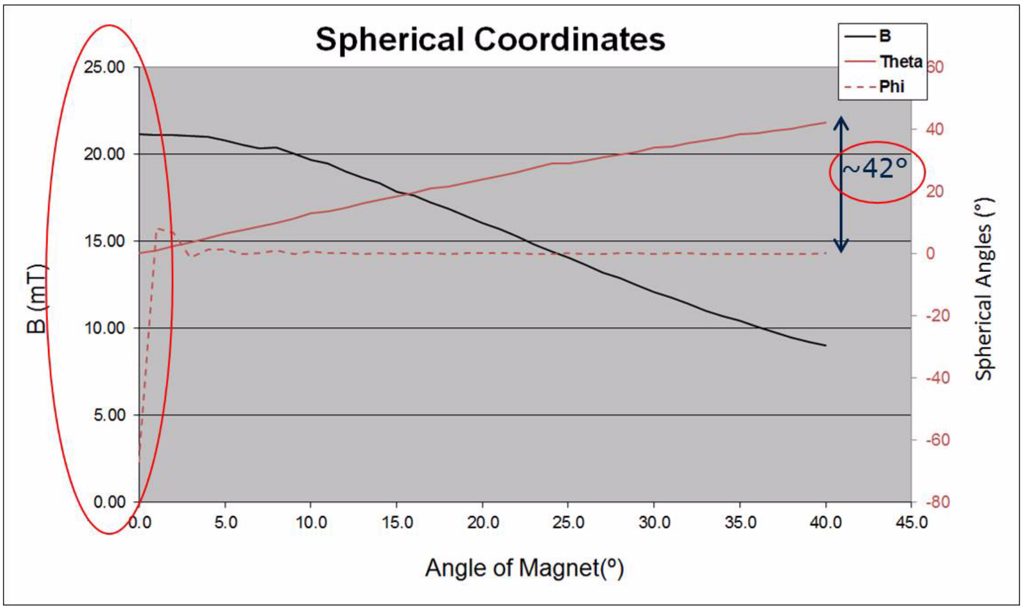


Figure 14 Cylindrical magnet (option 3)

Conclusion:

If a solution is needed to have the magnet in the center of rotation a cylindrical magnet is needed.

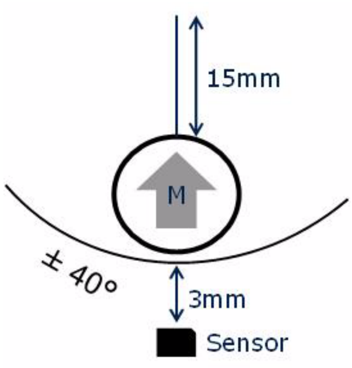
For realization the magnet below shall be used and the airgap may be reduced to 4 or 5 mm for best fit.

https://www.supermagnete.de/stabmagnete-neodym-rund/stabmagnet-durchmesser-3mm-hoehe-6mm-neodym-n48-vernickelt_S-03-06-N

4.4.3 Ball shaped magnet

Table 14 Parameters

Magnet	NdFeB
Magnetization	Diametral
Shape	Ball
B_r	900 mT
Ø	10mm
Lever	15 mm
Airgap	3 mm
Mechanical angle α	± 40°



The best performance can be realized with a ball shape magnet.

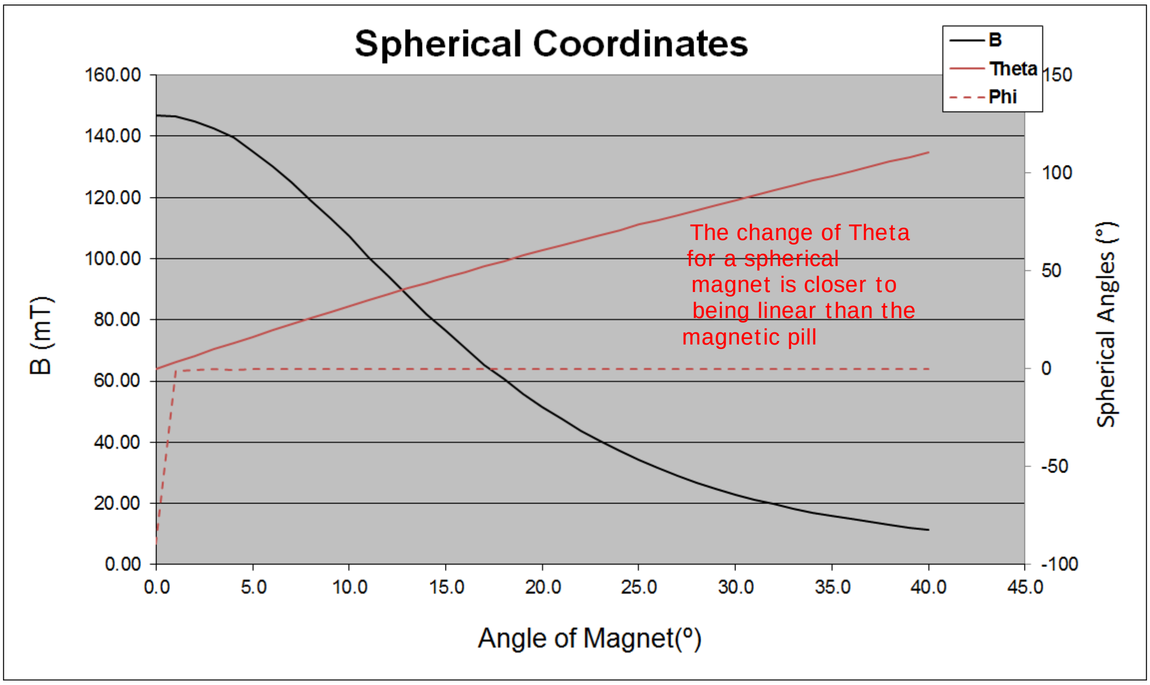


Figure 15 Ball shaped magnet

Results

- The change of Theta for a ball magnet is nearly linear.
- The magnetic field is always higher than 10 mT.

Conclusion:

Quite good for joysticks, but the cost position of the magnet is not at it's optimum.

5 Summary

With the new 3D sensor implemented in joystick, robust systems with small package can be enabled. Implementing 3D sensor in analog joystick removes the need for complex mechanics and brings better precision in usage of a joystick.

Further Information about the package can be found here:
http://www.infineon.com/cms/packages/SMD_-_Surface_Mounted_Devices/TSOP/TSOP6.html

Further Information about the 3D sensors can be found here:
www.infineon.com/3dmagnetic

For more information, please visit the website or contact Technical Support Infineon Technologies. We can attend to your concerns and help you most like to work together to find a solution to your concerns.

6 Appendix

6.1 Conversion from X,Y and Z coordinates to spherical coordinates

The readouts have been translated from X, Y & Z coordinates to spherical coordinates.

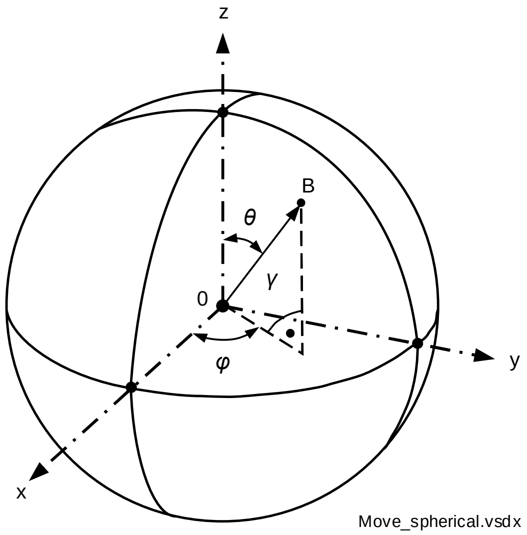


Figure 16 Movements in spherical coordinates

Following formulas have been used for the translation from cartesian to spherical coordinates:

The mag. flux density vectors are given by the following formulas:

$$x = r \cdot \sin\theta \cdot \cos\varphi$$

$$y = r \cdot \sin\theta \cdot \sin\varphi$$

$$z = r \cdot \cos\theta$$

→ r, x, y, z corresponds to Br, Bx, By, Bz

The sensor measures Bx, By, Bz (with some errors)

µC calculates:

$$r = \sqrt{x^2 + y^2 + z^2}$$

theta

$$\theta = \arccos \frac{z}{\sqrt{x^2 + y^2 + z^2}} = \arccos \frac{z}{r} = \frac{\pi}{2} - \arctan \frac{z}{\sqrt{x^2 + y^2}}$$

phi

$$\varphi = a\tan 2(y,x) = \begin{cases} \arctan(\frac{y}{x}), & if\ x > 0 \\ \operatorname{sgn}(y)\frac{\pi}{2}, & if\ x = 0 \\ \arctan\left(\frac{y}{x}\right) + \pi, & if\ x < 0 \wedge y \geq 0 \\ \arctan\left(\frac{y}{x}\right) - \pi, & if\ x < 0 \wedge y < 0 \end{cases}$$

7 Revision History

Revision	Date	Changes
1.0	2016-06-21	Initial release.

www.infineon.com

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