Using a Magnetic 3D Sensor in a Gear Stick Application

3D Magnetic Sensors

Application Note

Rev. 1.0 2015-10-15

Sense & Control

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1 Abstract

Target of this application note is to show how a magnetic 3D sensors can be used in a gear stick application.

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

A magnetic 3D sensor is well suitable for a detection of the position of the gear stick. The „State-of-the-art“ solution with up to 6 single hall switches can be replaced by one 3D sensor. The TLE493D-W1B6 has the same package dimensions as a hall switch and leads to cost and space savings.

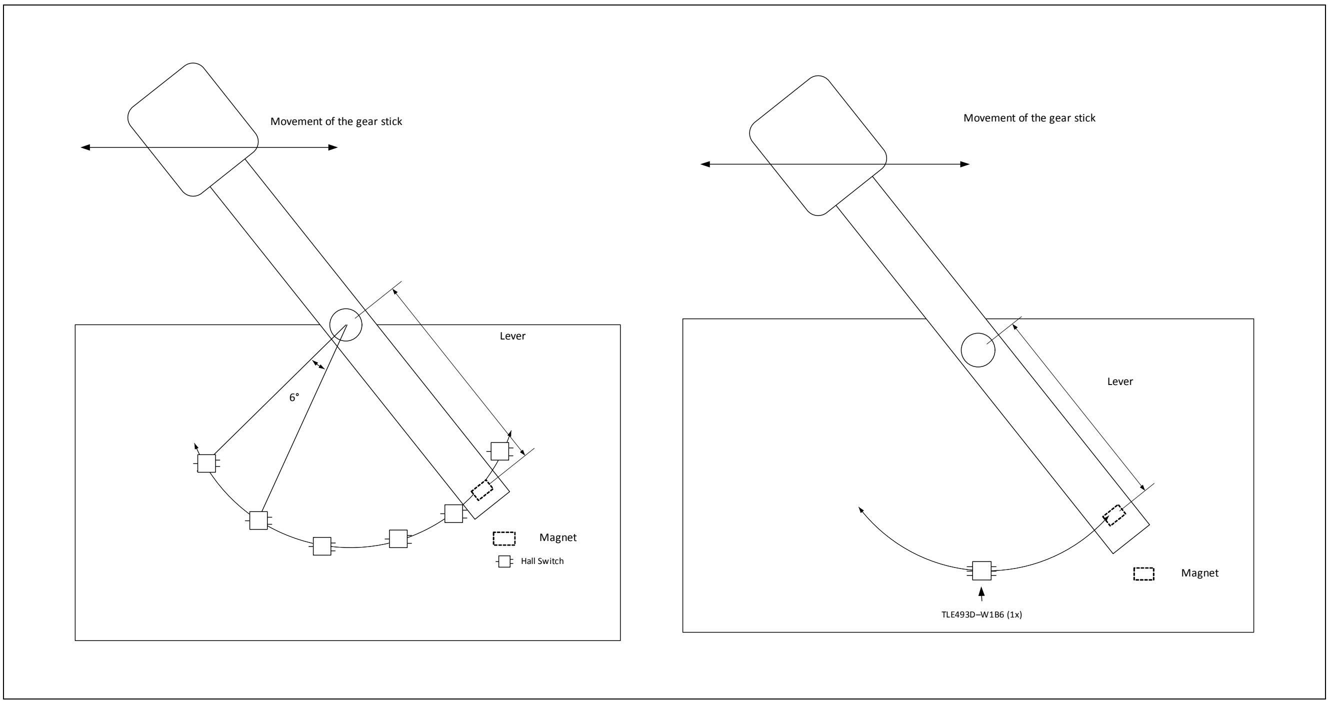

Figure 1 Principle of a position detection in a gear stick

The idea is that dedicated positions of a lever needs to be detected. For automated transmission normally following positions are required:

- P - Park
- R - Reverse
- N - Neutral
- D - Drive
- Optional „+“ and „-“ for “manual” gear shift

Up to now the detection is realized by a hall switch matrix on a PCB. Up to 6 simple Hall switches are needed to detect the gear position. Due to safety reasons often two switch arrays are necessary.

3 How to use a 3D Sensor?

For a robust design with a magnetic 3D sensor following parameters are used:

- Arc range 0° .. 30° (each 6° one Hall switch)
- Magnet Parameters
  - Material = NdFeB
  - Magnet shape= rectangular block (7mm x 5mm x 3 mm)
  - Airgap between sensor and magnet = 4mm
  - Magnetization direction = axial
  - Remanence Br = 1T
  - Lever = 1.3cm

With the above used parameters a linear characteristic between magnetic calculated angel theta Θ and mechanical movement of the gear stick is obtained. The spherical angle theta is calculated of the X, Y and Z components of the sensor, see **Chapter 6**. With those a clear position detection can be obtained.

The absolute value of the field is always in the range of around 30mT and is therefore considered as a sufficient signal.

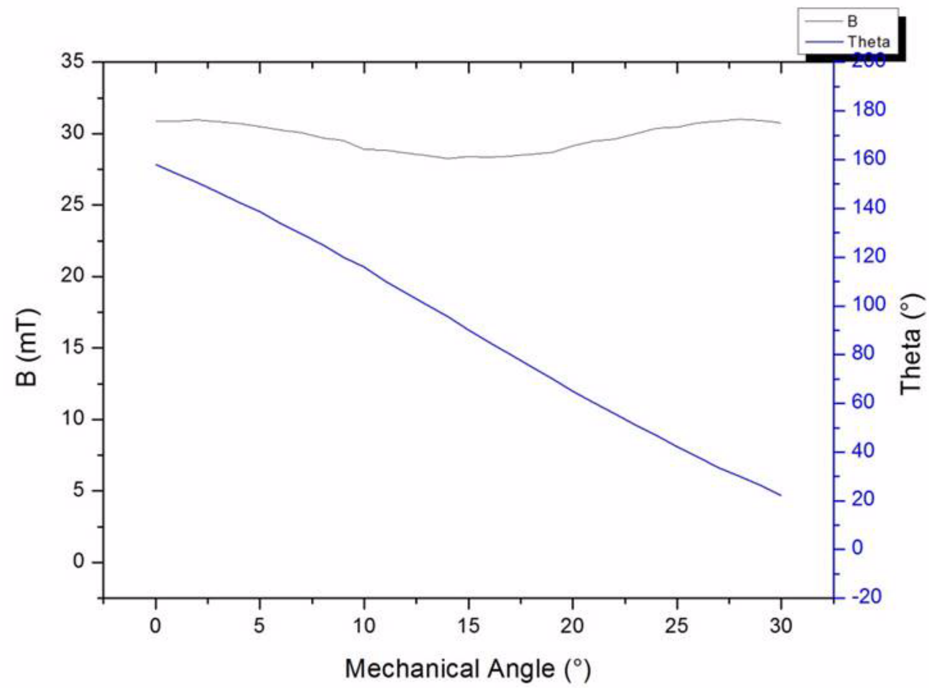

Figure 2 Mechanical Angle versus Theta

The linear range of theta depends on the length of the lever. The smaller the lever the bigger is the linear range (**Figure 3**).

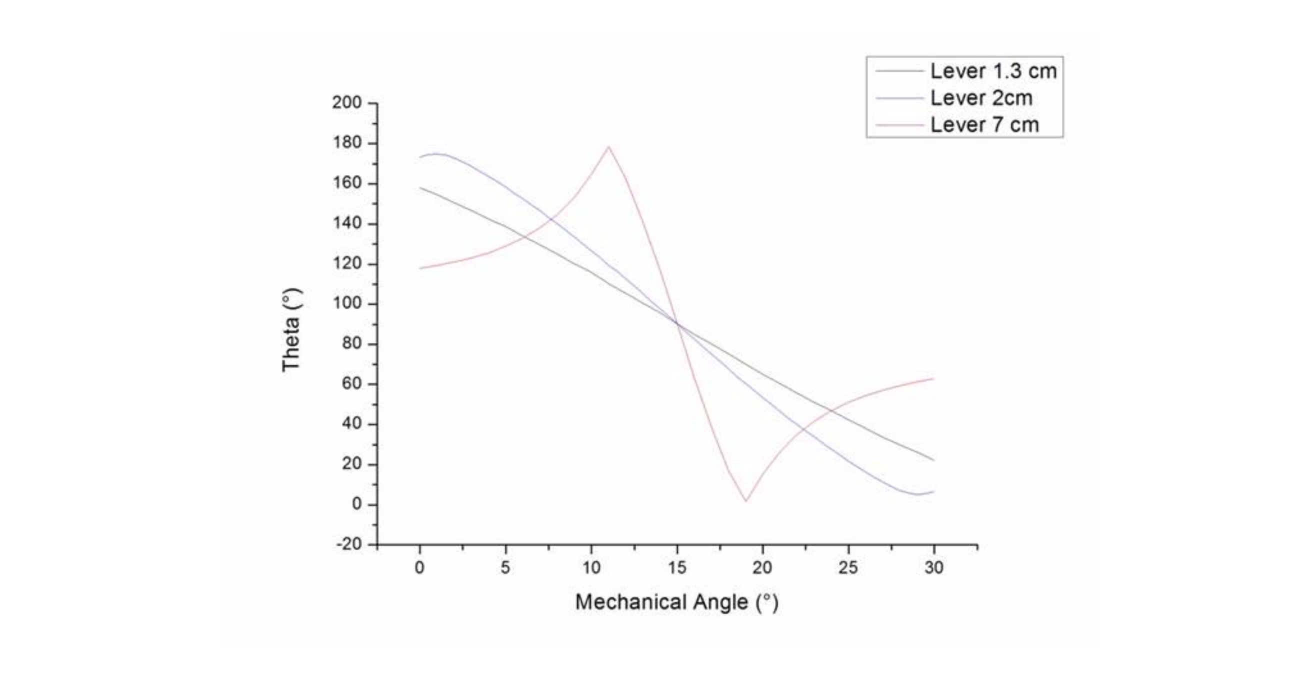

Figure 3 **Linear Range versus Lever Length**

Further simulations for a cheaper magnet have been evaluated. The magnet material NdFeB has been replaced by a ferrite. All other parameters have been kept the same.

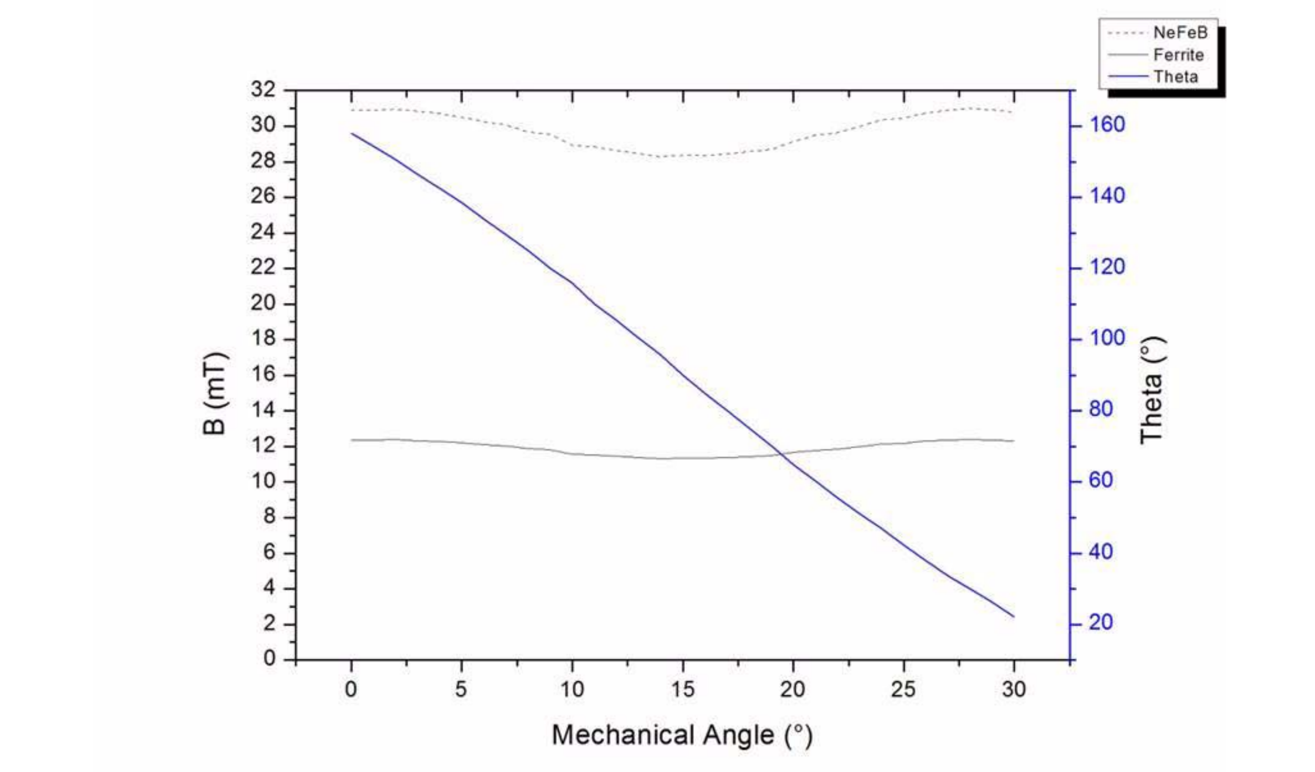

Figure 4 **Influence of Magnetic Material; Mechanical Angle versus Theta**

As you can see in **Figure 4** the linear range has not changed, but the strength of the magnetic field has decreased. If this still fits the application needs than you are fine with a ferrite.

But, you may come up with some concerns that the robustness is not sufficient anymore due to the smaller field. This decline of field can be compensated by a reduction of the airgap from 4mm to 2mm. This is shown in **Figure 5**.

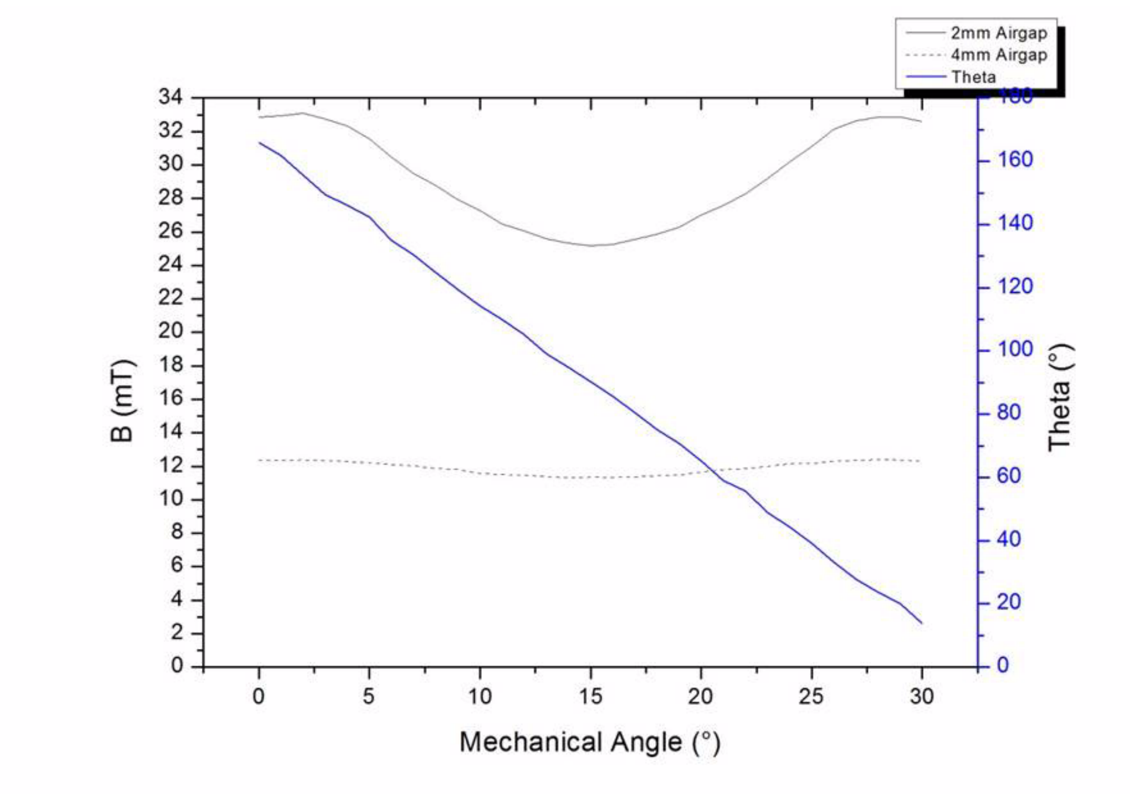

Figure 5 Reduction of Airgap with Ferrite

All those simulations give a good indication for a proper magnetic design as position detection in a gear stick application.

This simulation will be verified in the future.

4 Accuracy

The accuracy is evaluated for below mentioned parameters:

Geometry:

- Lever: 1.3 cm
- Airgap: 4 mm

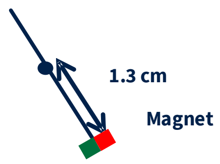

Figure 6 Magnet Lever

Magnet:

- Size: 7x5x3 mm
- Remanence: 1000 mT
- Magnetization: axial

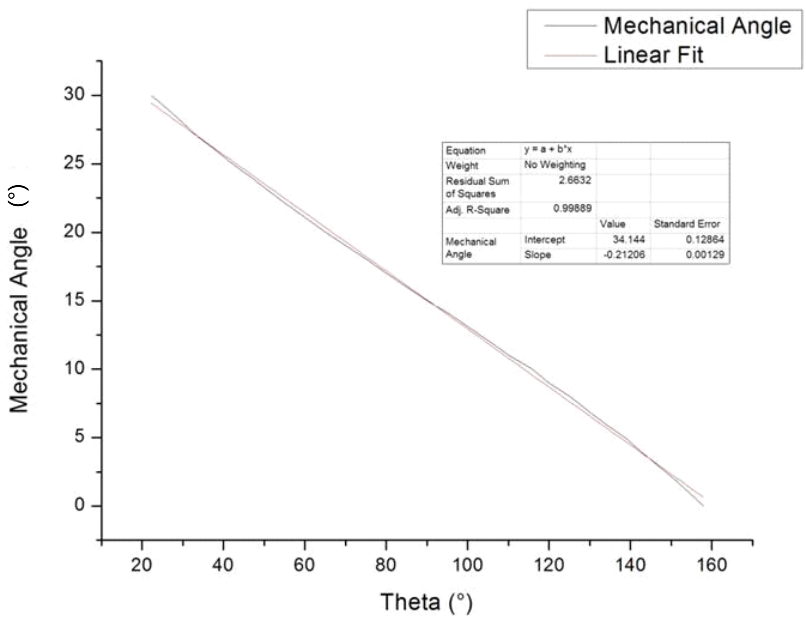

Figure 7 Linear Fit of the Mech. Angle

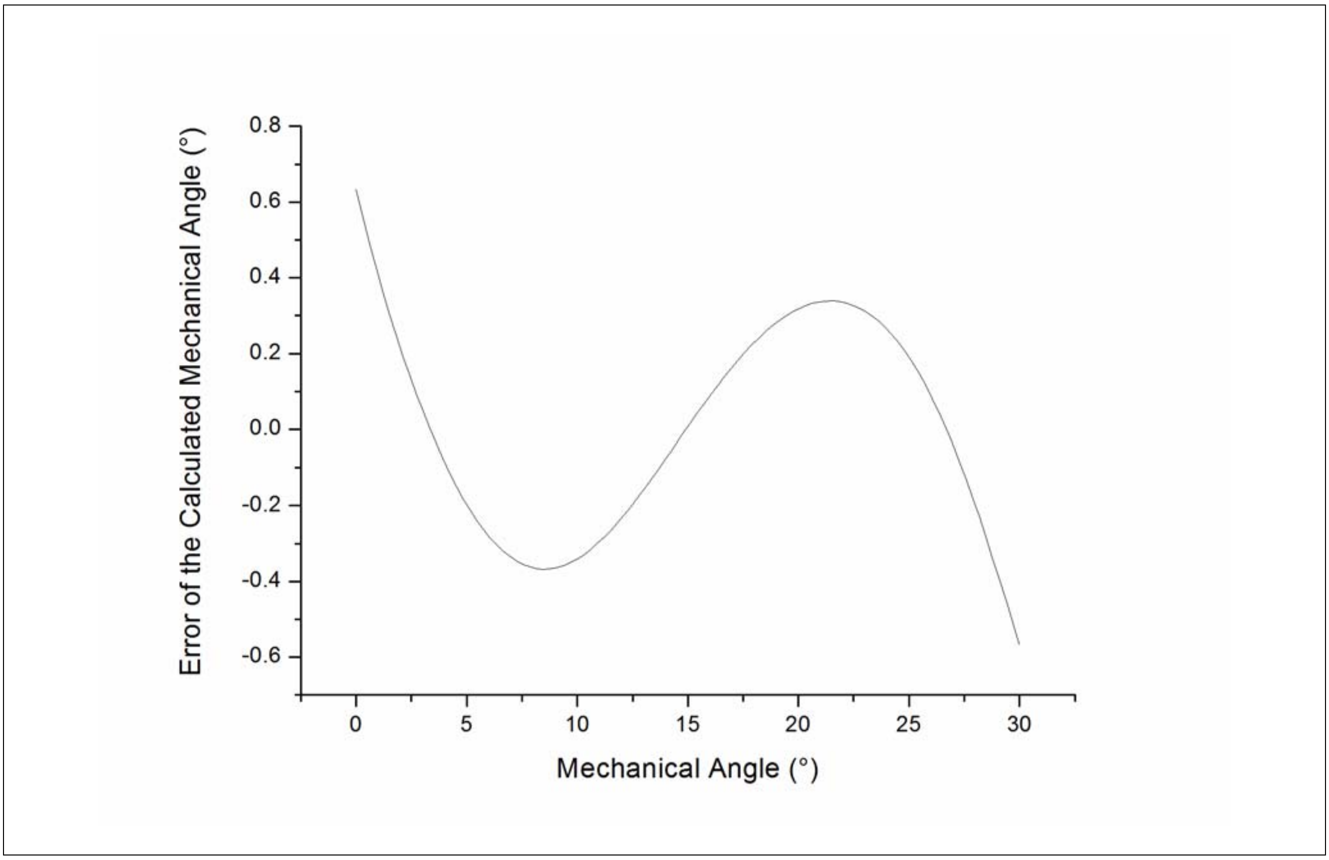

Figure 8 Error of the Linear Fit Compared to the Original Value

Result:
The error is below 1° for an ideal magnetic circuit. Sensor errors may lead to additional errors.

5 Sensor Functionality

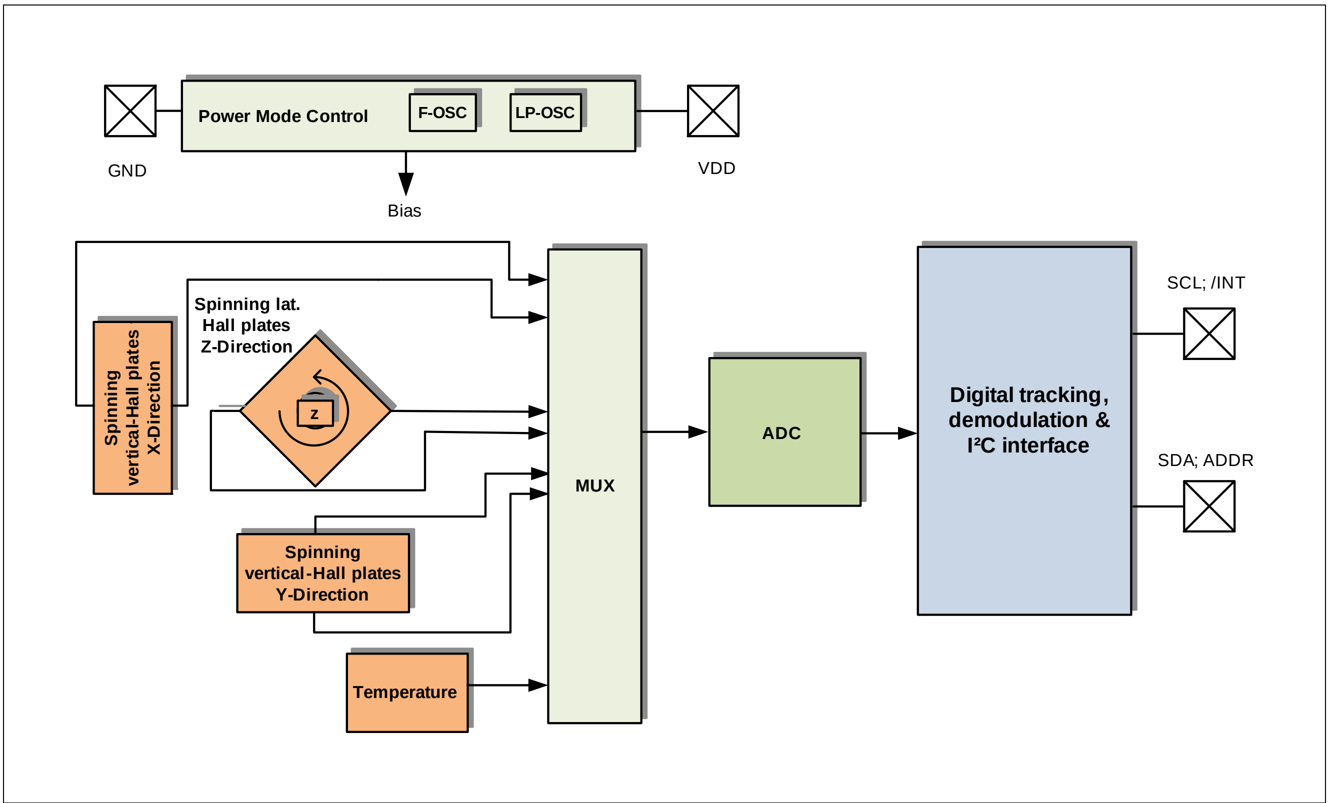

Figure 9 Block Diagram

The IC consists of three main function units containing following building blocks:

- The power mode control system, containing a low-power oscillator, basic biasing, accurate reset, undervoltage detection and a fast oscillator.
- The sensing part, containing the HALL biasing, HALL probes with multiplexers and successive tracking ADC. Furthermore a temperature sensor is implemented.
- The I^{2}C interface, containing the register file and I/O pads

5.1 Sensing part

Performs the measurements of the magnetic field in X, Y and Z direction. Each X, Y and Z-HALL probe is connected sequentially to a multiplexer, which is then connected to an Analog to Digital Converter (ADC). Optional, the temperature is determined as well after the three HALL channels. The current consumption decreases by -25% when temperature measurement is deactivated.

6 Appendix: Calculation of Spherical Coordinates

6.1 Generals in 3D Movements

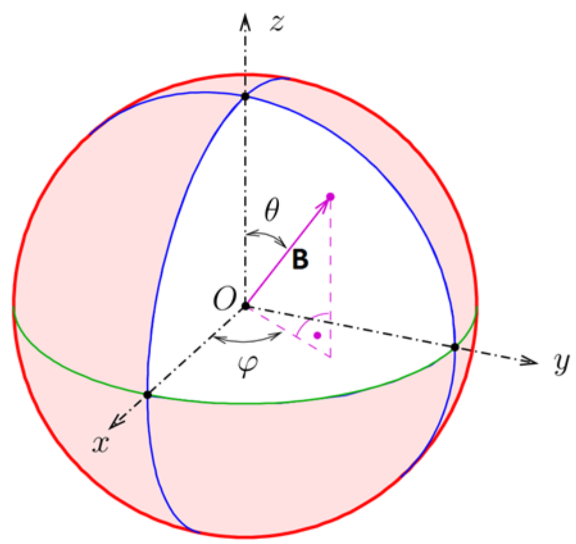

Figure 10 Spherical Movements

- In the Zero position (=Z-axis) Phi=0° & Theta=0°
- A pure forward or backward movement along the x-axis will lead to an increasing absolute Theta value. Phi will stay at 0°
- A pure left or right movement along the y-axis will lead to an increasing absolute Theta value. Phi will jump from 0° to 90°
- All other movements/positions can be described as a combination of Theta & Phi

6.2 Conversion from X,Y and Z Coordinates to Spherical Coordinates

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

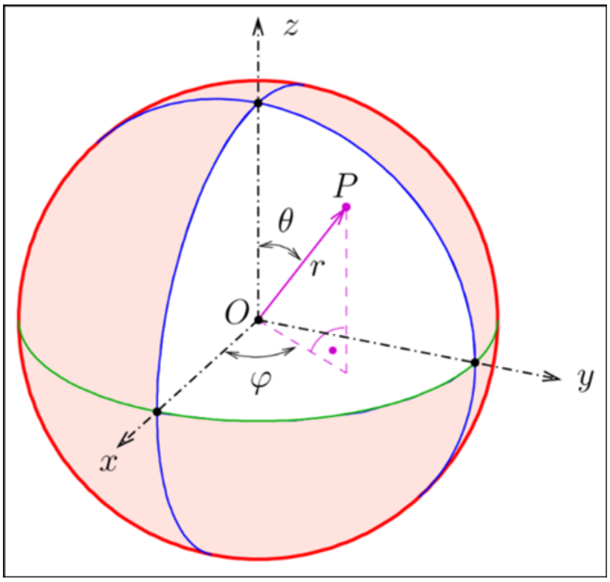

Figure 11 Movements in spherical coordinates

Following formulas have been used for this translation:

Mag. flux density vectors given by mechanics

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

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

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

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

with Br = vector length of magnetic field

Bx = field component in x-direction

By = field component in y-direction

Bz = field component in z-direction

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

$$\varphi = \text{atan2}(y,x) = \begin{cases} \arctan\left(\frac{y}{x}\right) & \text{, if } x>0 \\ \text{sgn}(y)\,\frac{\pi}{2} & \text{, if } x=0 \\ \arctan\left(\frac{y}{x}\right) + \pi & \text{, if } x<0 \wedge y\geq 0 \\ \arctan\left(\frac{y}{x}\right) - \pi & \text{, if } x<0 \wedge y<0 \end{cases}$$

7 Revision History

Revision	Date	Changes
Rev. 1.0	2015-10-15	

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