Angle Sensors

GMR-Based Angular Sensors

Magnet Design

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Application Note

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1 Introduction

Giant Magneto Resistance (GMR) sensors are used as position sensors in automotive and industrial applications. They detect the orientation of an external magnetic field, which is rotating above the sensor. This magnetic field is generated by a permanent magnet with diametrical magnetization.

The sensor itself is only sensitive in xy-plane. Through assembly tolerances also z-components are projected into the xy-plane and cause an additional angle error. **Independent of the used sensor principle (Hall effect, magneto resistive effect) assembly tolerances cause an additional angle error, which we call assembly error.** The smaller the sensitive area the smaller this additional angle error.

Two points have to be considered for the right choice of magnet:

- Magnetic field strength at the sensitive area of GMR is in the specified range
- Magnetic field must be sufficient homogeneous at the sensitive area of GMR, to keep influences from assembly tolerances as small as possible (subject of this application note).

2 Magnet - Sensor Setup

The GMR-sensor needs a magnetic field strength in xy-plane of 30 to 50mT over the whole temperature range. If the maximum temperature is limited the magnetic field strength may be larger (see latest datasheet specified type of angle sensor).

Figure 1 shows a typical magnet-sensor setup. The origin of the coordinate system lies on the axis of rotation if we neglect all assembly tolerances. Along this axis any point is allowed as origin. It could be the gravity center of the magnet or it could be the point where the rotation axis crosses the surface of the magnet. Infineon Technologies prefers to use the center of highest symmetry for the magnet. It is important to keep this origin constant during all subsequent stages of optimization.

The z-axis of the coordinate system is identical to the axis of rotation if we neglect all assembly tolerances.

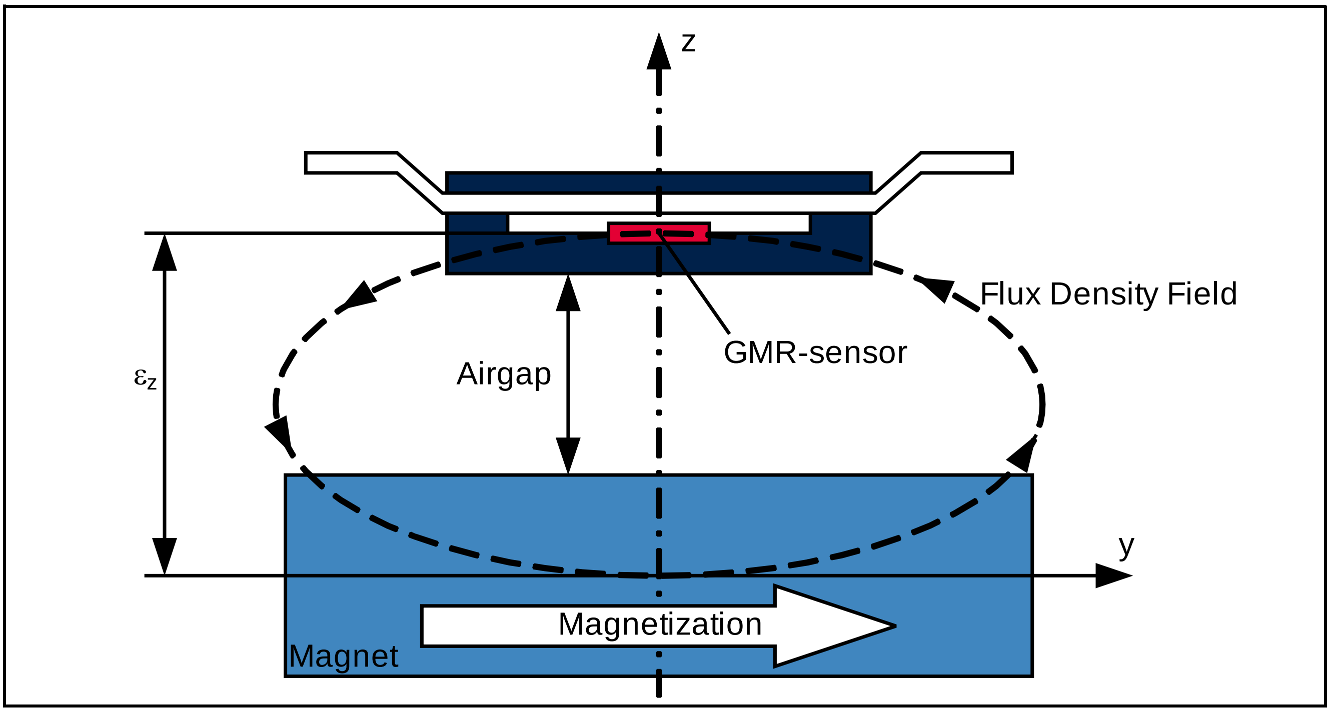

Figure 1 Magnet-Sensor Setup

The magnetization vector of the magnet has to point in positive y-direction. Consequently, on the GMR-sensor the flux density vector points in negative y-direction.

3 Calculation of Assembly Error

Assembly tolerances like tilt and eccentricity of magnet and sensor with respect to the axis of rotation lead to an error in the measured angle - assembly error. This chapter shows how to calculate and minimize this error.

First of all the GMR sensitive area has to positioned on the axis of rotation in $z = \varepsilon_z$.

$$\left|B_Y(0,0,\varepsilon_z)\right| = 40mT \tag{1}$$

Following equations can be calculated via finite-element simulation:

Eccentricity-shape function:

$$E(\varepsilon_z) = \frac{1}{\left|B_y(0,0,\varepsilon_z)\right|}\frac{\partial^2 B_y(0,0,\varepsilon_z)}{\partial x \partial y} \tag{2}$$

Tilt-shape function:

$$T(\varepsilon_z) = \frac{-1}{\left|B_y(0,0,\varepsilon_z)\right|}\frac{\partial B_z(0,0,\varepsilon_z)}{\partial y} \tag{3}$$

The following parameters specify the worst case assembly tolerances:

- Worst case tilt angle of magnet against axis of rotation (β)
- Worst case tilt angle of GMR-sensor against axis of rotation (λ)
- Worst case eccentricity of magnet against axis of rotation (δ_r)
- Worst case eccentricity of center of sensitive area of GMR-sensor against axis of rotation (ε_r)

If these parameters are known, the maximum additional angle error can be calculated by **Equation (4)**.

$$ME_{15} = \left(\frac{\beta}{2}\right)^2 \left|1 + 2\varepsilon_z(T + \varepsilon_z E)\right| + \left(\frac{\lambda}{2}\right)^2 + \beta\lambda\left|1 + \varepsilon_z T\right| +$$
$$(\varepsilon_r + \delta_r)\left[\frac{\beta}{2}\left(|T| + |T + 2\varepsilon_z E|\right) + \lambda|T|\right] + \frac{|E|}{2}(\varepsilon_r + \delta_r)^2 \tag{4}$$

Note that ME_{15} is an estimation, which may over-estimate the real angle error by a factor of 1.4, yet it does by no circumstances under-estimate the real assembly error. Hence the real maximum assembly error can be calculated by **Equation (5)**. It is the maximum difference between apparent angle and real mechanical angle.

$$\max\left(\left|angle\_apparent - angle\_mechanical\right|\right) = (0.71..1.0)ME_{15} \tag{5}$$

The magnet is suitable for the angle sensor if it fulfills the following requirements:

- **Equation (1)**

If the flux density is too weak, it is possible to use a stronger magnet material with higher remanence or increase the volume of the magnet or reduce the distance of magnet to GMR-sensor.

- ME_{15} is small enough

If ME_{15} is too large, it is possible to increase the diameter of the magnet or reduce the distance of magnet to GMR-sensor or reduce the assembly tolerances or modify the shape of the magnet.

Examples for different magnet designs and their additional maximum angle error

The errors in **Table 1** are calculated for cylindrical magnets with the following parameters:

- Tilt angle of magnet against axis of rotation (β = 1°)
- Tilt angle of GMR-sensor against axis of rotation (λ = 2°)
- Eccentricity of magnet against axis of rotation (δ_r = 0.25mm)
- Eccentricity of GMR-sensor against axis of rotation (ε_r = 0.2mm)

Table 1 Examples of Different Magnet Dimensions

Thickness [mm]	Diameter [mm]	Airgap [mm]	B_{rem} [mT]	ME_{15} [°]
2.5	20	0.5	675	0.16
2.5	20	1	695	0.17
2.5	20	2	750	0.19
2.5	10	0.5	390	0.36
2.5	10	1	425	0.36
2.5	10	2	540	0.43
4	20	1	465	0.18
4	20	3	565	0.19
4	10	1	315	0.37
1	5	1	635	1.02
2	5	2	720	1.24
8	5	0.5	210	0.93

4 Optimized Magnet Design

Increasing the diameter of the magnet reduces the error drastically. Doubling the diameter gives 3 times smaller assembly error. In fact the larger diameter leads to smaller shape functions *E* and *T* and this leads to smaller assembly errors. Generally Infineon Technologies suggests to use a diameter of at least 10mm.

It is possible to choose a particular shape of the magnet in order to achieve small shape functions *E* and *T*. This can be done by a cylindrical magnet with a stud hole facing the GMR-sensor (**Figure 2**).

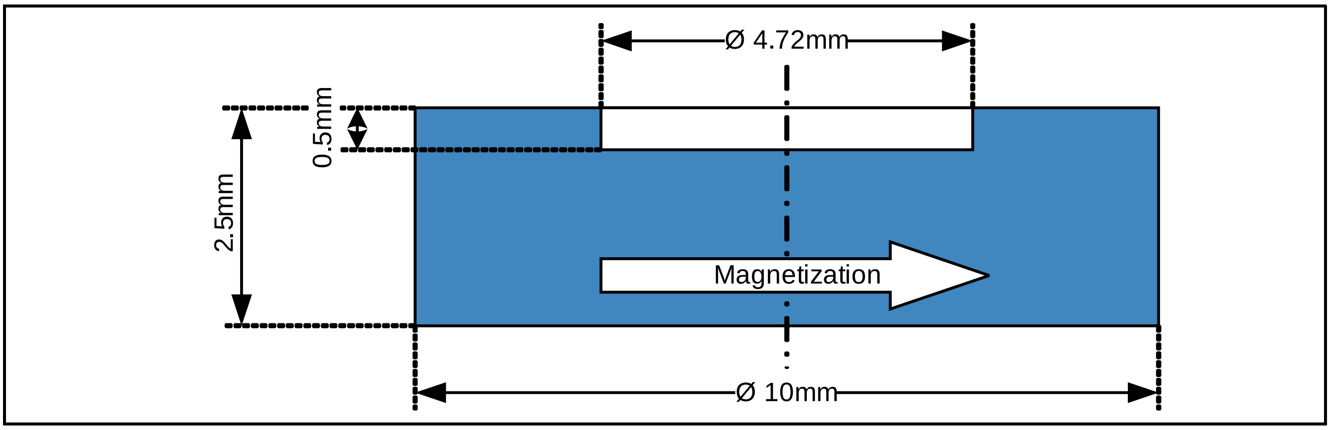

Figure 2 Optimized Magnet Shape

Table 2 **Examples of ME_{15} with Optimized Magnet Shape**

Thickness [mm]	Diameter [mm]	Airgap [mm]	B_{rem} [mT]	ME_{15} [°]
2.5	10	0.5	690	0.06
2.5	10	1	700	0.29
2.5	10	2	738	0.39

References

[1] U.Ausserlechner, “Inaccuracies of Giant Magneto-Resistive Angle Sensors due to Assembly Tolerances”, IEEE Trans. Magn., May 2009, vol. 45, no. 5, pp. 2165-2174

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