Application Guidelines for Using GMEMS' Geomagnetic Sensor

Introduction

This technical note serves as the first pivotal point for users to successfully adopt GMEMS' geomagnetic sensor for consumer electronic compass (e-Compass) application. The foundation will first be laid by introducing the nature of geomagnetic field and the operating principle of the e-Compass. The pitfall in the field application is then illustrated to understand the magnetic interference by the hard/soft iron effects and PCB current. Finally the placement suggestions and material selection guidelines are highlighted to facilitate the successful deployment of GMEMS' geomagnetic sensor.

Geomagnetic Field and e-Compass

Geomagnetic Field

The geomagnetic field is the magnetic field created by the earth, which acts like a great spherical magnet. In general such earth magnet can be viewed as a dipole magnet located at the center of the earth, with the S magnetic pole near the North Pole and N magnetic pole near the South Pole. Because the axis of the dipole is offset from the axis of the earth's rotation by about 11 degrees, the north and south magnetic poles are slightly different from those geographic poles, as shown in the Figure 1.

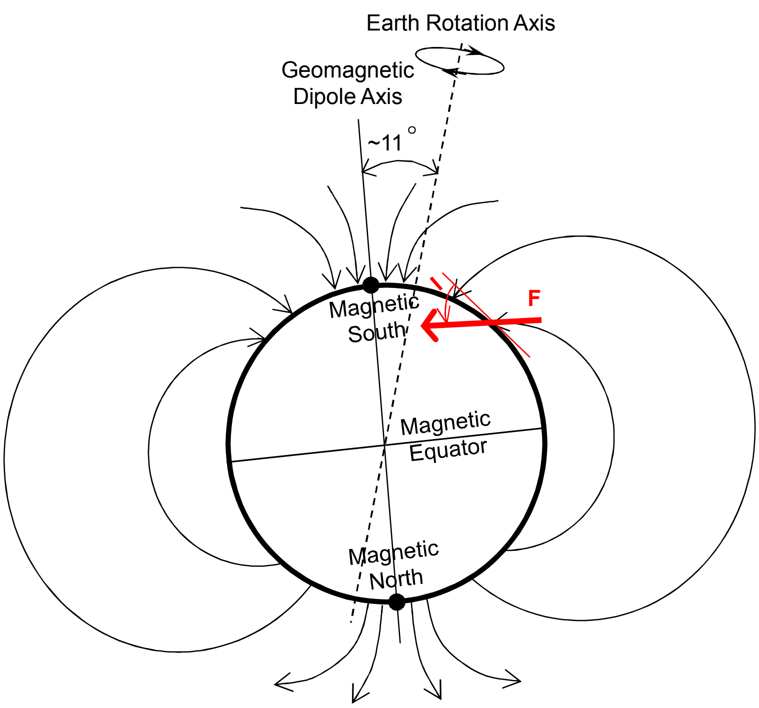

Figure 1：Geomagnetic Field from the Earth Dipole Magnet

The geomagnetic field is characterized by a direction and intensity. The direction and intensity of the geomagnetic field change with both locations and time. For example, the magnetic field lies parallel to the ground at the magnetic equator, and is almost vertical near the magnetic poles.

The geomagnetic field can be described by the following parameters:

1. Declination (D): measured in units of degrees. Magnetic declination is the angle difference between the magnetic north and true north, Figure 2.
2. Inclination (I): measured in units of degrees. Magnetic inclination is the angle between the horizontal plane and the total geomagnetic field vector, measured positive into earth, Figure 1.
3. Horizontal Intensity (H): the horizontal component of the total geomagnetic field, Figure 2. The horizontal component can be further decomposed to
   - North (X) component of the horizontal intensity, Figure 2.
   - East (Y) component of the horizontal intensity, Figure 2.
4. Vertical Intensity (Z): the vertical component of the total geomagnetic field, Figure 2.
5. Total Intensity (F): the magnitude of the total geomagnetic field, Figure 1 and 2.

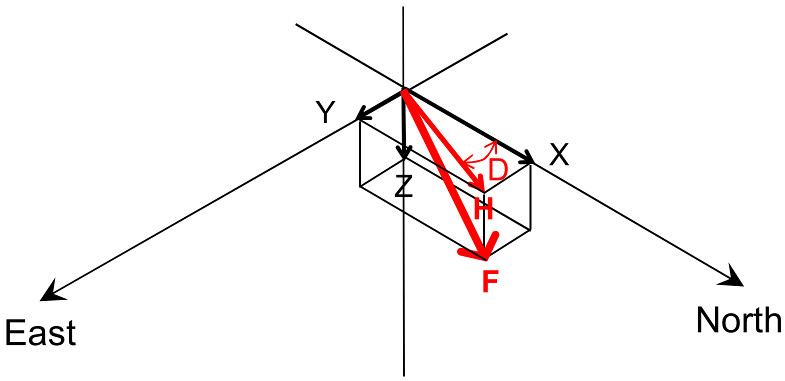

Figure 2: Geomagnetic Field Parameters

Magnetic Intensity Units

Magnetic field intensity such as H, X, Y, Z, and F may be measured in gauss, but are generally reported in milli-tesla (mT) or micro-tesla (uT). The conversion between these units is

$$1\,\text{gauss} = 0.1\,\text{mT} = 100\,\text{uT}$$

Compass and e-Compass

A compass is a navigation device that shows directions relative the surface of earth. The magnet compass is one of the greatest inventions that can be traced back to 247 BC China. It basically contains a dipole magnet, typically in the shape of a needle, which can interact with the earth's geomagnetic field, whose intensity is around 25~65uT, to align itself to the field direction. As shown in the Figure 2, the horizontal component (H) of the geomagnetic field is the one that can actually give us the direction. The vertical component (Z) just causes the tilting of the needle.

The e-Compass has no such rotating mechanical needle inside, but instead uses magnetometer to detect the geomagnetic field and the direction can be "calculated" from the sensor readouts. For example if we place an e-Compass horizontally as shown in the Figure 3, the e-Compass will pick up the horizontal component (H) by the X- and Y-axis readings. The direction angle can be simply calculated by $\tan^{-1}\left(\frac{\text{X - axis Reading}}{\text{Y - axis Reading}}\right)$.

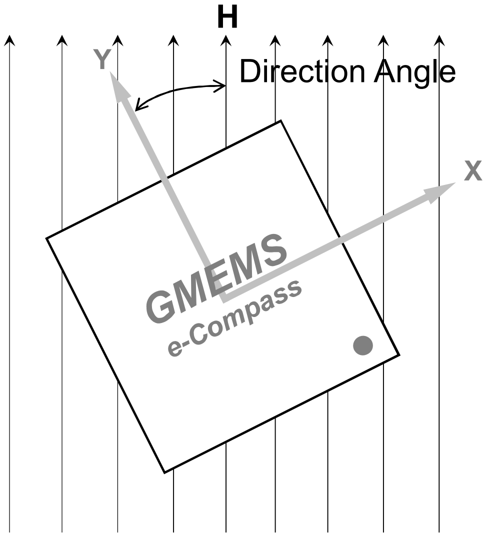

Figure 3: Electronic Compass and Direction Angle

In general application, the e-Compass may be used when tilts from the horizontal plane. In such case instead of the horizontal component (H), we need to sense the total geomagnetic field (F) and the tilting angle in order to calculate the correct direction angle. A 3-axis geomagnetic sensor like GMEMS' GME303 can precisely measure the geomagnetic field (F). Further tilt compensation can be accomplished by calculating the tilt angle from the static reading of a 3-axis accelerometer like GMEMS' GMA303 to provide precise navigation heading.

Magnetic Interference and Sensor Placement

Any compass, magnetic or electronic alike, interacts with the weak geomagnetic field to give directions. The earth's total magnetic field intensity (F) is so weak at about 25~65uT that is easily subject to magnetic interference. For example in a typical mobile device, a naïve speaker may create a magnetic field up to a 37,000uT at its vicinity, much higher than the geomagnetic intensity we are interested in. Fortunately the magnetic field intensity decays very rapidly by distance. The key point to circumvent magnetic interference is to identify troubling components and keep compass a safe distance away from them.

Below summarize the often seen magnetic interferences:

I. Hard iron effect: caused from permanent Ferro-magnets. Usually found in the components like speakers, buzzers, and vibrators. The interference is a fixed additional magnetic field upon the geomagnetic one. In general hard iron effect can be compensated by the calibration software.

II. Soft iron effect: caused from components with large relative magnetic permeability. It distorts the surrounding magnetic field because of its large relative magnetic permeability. Soft iron effect generally can also be compensated by the calibration software.

III. PCB current: caused by current flows. Fixed current will cause fixed magnetic field adding to the hard iron effect, which can be compensated by the calibration software. However the current fluctuation will introduce transient magnetic interference that is difficult to compensate by the calibration software.

Hard Iron Effect

Hard iron effect is the magnetic field generated from permanent Ferro magnets, usually found in components like speakers, buzzers, and vibrators. Since the components are fixed in locations on the PCB with fixed magnetic intensity, the resulting interference is a fixed additional magnetic field upon the geomagnetic one. In general such fixed hard iron effect can be compensated by the calibration software.

The important point to note is that the calibration software can help only when the e-Compass is still working. If the hard iron effect is so strong that saturates the e-Compass, there is nothing we can do further. Thus it's always a good idea to avoid components with large hard iron effects, and always keep a safe distance from them in order to limit the interference safely within e-Compass's working range.

Table 1 lists some common components with hard iron effects and the typical minimum distance for safe e-Compass placement. GMEMS' e-Compass is designed with the magnetic interference in mind. For example GME303 has a rather large dynamic range of ±4914uT, that is 75~200 times of the geomagnetic intensity. This large dynamic range helps reduce the safe distance, giving system engineers more freedom to integrate GMEMS' e-Compass.

The rule of thumb for clearance distance is to keep the interference magnetic field intensity no more than half of the e-Compass dynamic range. For example in GME303's case, we recommend the minimum safe distance is to make sure the interference magnetic field intensity stay below 2457uT, or half of the GME303's 4914uT dynamic range.

Hard Iron Components	Magnetic Intensity at Surface	Typical Minimum Safe Distance
Audio Receiver	20,000uT	10~20 mm
Magnet proximity sensor	255,000uT	30 mm
Hinge	12,000uT	10 mm
Camera module	7,000uT	10 mm
Speaker	37,000uT	20~30 mm
Vibrator	14,000uT	10 mm

Table 1: Typical Components with Hard Iron Effects

Soft Iron Effect

Soft iron material does not generate strong magnetic field by itself. Instead it distorts the surrounding magnetic field because of its large relative magnetic permeability. The appearance of this influence depends on the incident angle of the magnetic flux. When a soft iron material is located closely to the compass device, no compass can detect correct geomagnetic field, resulting in wrong direction angle.

Soft iron effects are more complex to compensate than the hard iron effects because the distorted field depends on the relative orientation of the geomagnetic field to the soft iron components. For components used in mobile devices, this soft iron effects induced by the geomagnetic field will therefore depend on the device orientation. Thus soft iron effect generally poises a greater challenge for the calibration software to compensate.

Figure 4 illustrates the distortion of a uniform magnetic field by a soft iron component. Any compass within its distorted range will measure a magnetic field with a very significant direction angle error. Furthermore the direction angle error will depend on the relative orientation of the magnetic field to the soft iron component, making it difficult for compensation.

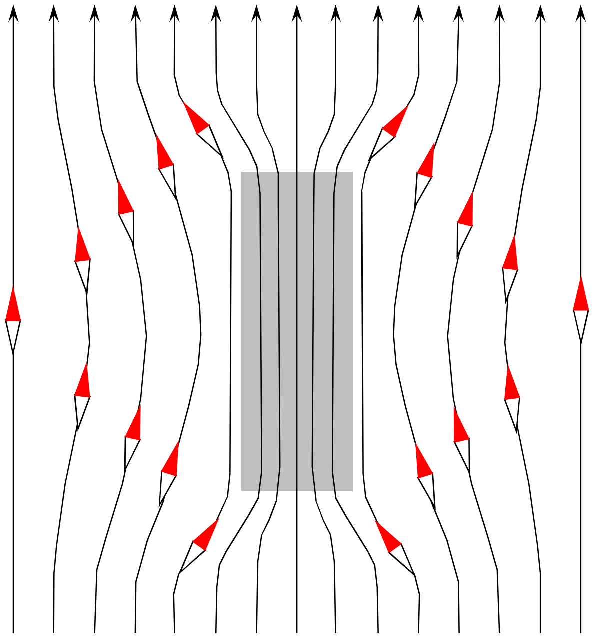

Figure 4: Soft Iron Effect

To avoid soft iron direction angle errors, it is recommended to remove such material or change the material to non-ferromagnetic one. If such measure is not applicable, a safe distance from those soft iron components is the best strategy we can take. Table 2 lists some common soft iron components and typical minimum safe distances. The rule of thumb for design check is to make the soft iron direction angle error less than 3°.

Soft Iron Components	Typical Minimum Distance
Memory card slot	5 mm
Hinge	5~10 mm
Connectors	5 mm
Metal shield and frame	5 mm
Magnetic sheet for RFID or noise	10 mm
Battery	10 mm

Table 2: Typical Components with Soft Iron Effects

PCB Current

PCB current effect can be modeled as a magnetic field generated by a straight wire with a steady current, as illustrated in Figure 5. The magnetic field by such current can be described by

$$B = \frac{\mu_0 I}{2\pi R}$$

where

B is the magnetic field intensity in T

$\mu_0 = 4\pi \times 10^{-7} \mathrm{N} \cdot \mathrm{A}^{-2}$ is the vacuum permeability

I is the steady current in A

R is the distance from the wire in m

The steady current will cause a fixed magnetic field similar to the hard iron effect. Table 3 lists the steady current effects for reference.

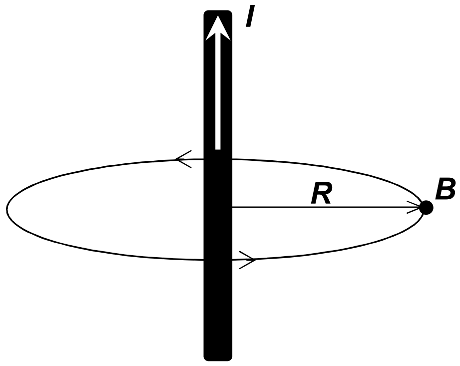

Figure 5: Magnetic Field around a Steady Current Wire

Steady Current I (A)	Typical Minimum Safe Distance (mm)
1	0.5
2	1
5	2

Table 3: Steady Current Effect

Current Fluctuation ΔI (mA)	Typical Minimum Safe Distance (mm)
2	0
10	3
50	7
100	18
200	25 or more

Figure 4: Fluctuation Current Effect

However it is not the steady current but the current fluctuation instead that dominates the magnetic interference problem. The steady current effect is similar to the hard iron effect that can be compensated by calibration software. But the current fluctuation will introduce transient magnetic interference that is difficult to be captured and compensated, and will contribute the magnetic noise picked up by the e-Compass. Table 4 lists the fluctuation current effect and recommended safe distance for reference.

Material Selection Guidelines

Iron, cobalt, nickel, and various their alloys are called ferromagnetic materials that can be permanently magnetized through exposure to an external magnetic field. Ferromagnetic materials are the major sources of interference for the hard iron effect. They are usually found in components like speakers, buzzers, vibrators, camera modules, magnetic proximity sensor, TV antenna, and track-ball.

Some iron, cobalt, nickel and their alloys are paramagnetic instead of magnetic. Paramagnetic material is only attracted when in presence of external magnetic field, usually having a relative magnetic permeability greater than unity. They are the major sources of interference for the soft iron effects. Ferritic- (400 series) and Martensitic- (600 series) stainless steel are paramagnetic. Keep a safe distance to avoid such soft iron effect.

Pure Austenitic stainless steel is non-magnetic, however in practice it is rather difficult, if not impossible, to achieve 100% Austenitic. There always exists some small percentage of Ferritic- and Martensitic-structure in the steel. Therefore the so called Austenitic-stainless steel (300 series) is subject to scrutiny for soft iron effect. For example SUS305 is generally non-magnetic. SUS301, SUS304 and SUS316 are nearly non-magnetic but special attention to double check is advised. The components with soft iron effects can usually be found in shield-can, screw, LCD frame, LCD back cover, housing frame, hinge, shields in RF module, and battery.

Non-magnetic materials are safe to use in the proximity of the e-Compasss, which includes copper and its alloy, aluminum, magnesium, brass (Cu+Zn), SUS305, titanium, gold, and silver. They are safe to use in the vicinity of e-Compass.

Document History and Modification

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