# COMPASSES/MAGNETOMETERS

MAGNETIC DISTORTION

Distortions in the magnetic field are often observed within electronic devices and can affect the accuracy of the compass or magnetometer. There are two basic types of magnetic field distortion, Hard Iron Distortion and Soft Iron Distortion.

HARD IRON DISTORTION

Hard Iron Distortion is the scaling of the sensed magnetic field, caused by magnetized or rare earth magnetic materials. This particular distortion generates a constant additive field to the magnetic field of the earth, creating a constant shift/offset from the origin of a magnetic field. These effects happen regardless of position/orientation of the sensing platform. Common devices which cause hard iron distortion include speakers, motors, and auto-focus actuators.
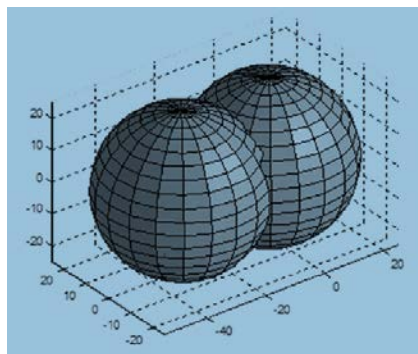
## Additive Fields and the Effects of Hard Iron Materials

Hard Iron Effects
- Can be easily calibrated
- Only require the knowledge of the offset from the origin
- Are compensated for by subtracting the offset directly from the measured data of the magnetometer

An ideal situation, in which no distorting effects are present, rotating a magnetometer a minimum of 360° and plotting the resulting data as X-axis vs. Y-axis, will result in a circle (or sphere, for a 3-dimensional approach) centered around (0, 0) (0, 0, 0 for a sphere). Of course, we usually do not operate in an ideal setting, so hard iron sources will offset the circle and/or sphere. To compensate for this effect, the circle/sphere needs to be "pushed back" to its original center point. Note, as long as the orientation and position of the magnet, relative to the sensor, is constant, the field and associated offsets will also be constant, and will easily compensate for the effect.

SOFT IRON DISTORTIONS

Soft Iron Distortions are the result of the magnetic field bending around materials interacting with a magnetic field. When placed near a sensor, the material may bend or attenuate the field, causing a reduction in sensitivity or angular accuracy of the compass. Soft iron distortions do not generate strong magnetic fields themselves, or distort/bend nearby magnetic fields, due to their relative magnetic permeability causing non-uniform sensitivity of the Earth's geomagnetic field. Common sources of soft iron distortion include iron, cobalt, nickel and their alloys, ferritic and martensitic stainless steels. These materials may be used in a wide variety of common components, including heat sinks, fasteners, hinges, connectors, batteries, spring steel dome switches, chip capacitors, and some integrated circuits. The change in a sensed magnetic field caused by soft iron distortion, has the effect of transforming the typically spherical sensed field into an ellipsoid.
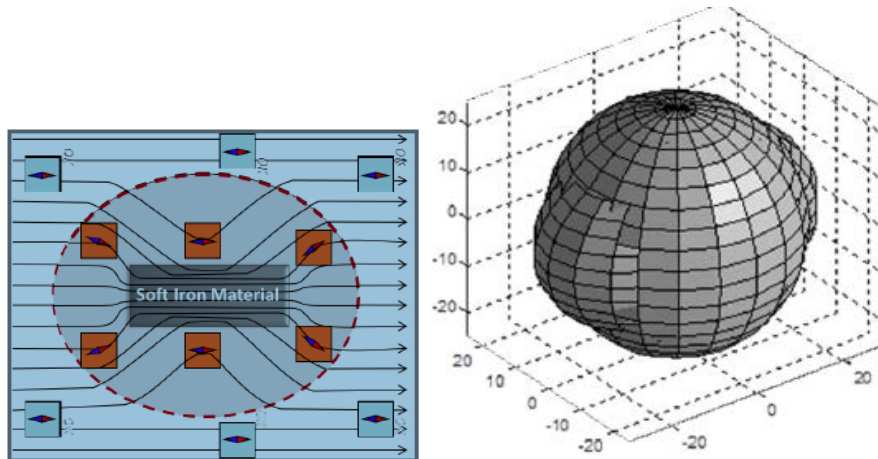
Soft Iron Effects

- Compensation is more difficult to calibrate and very compute intensive
- Require the characterization of the sensed magnetic field vs. sensor orientation, and an ellipsoid-based correction beforehand

Effects of Soft Iron

For soft iron distortion to be corrected, one must first identify the sources of soft iron interference (e.g. shields, buttons, screws, etc.) Soft iron effects will show up as pushing a perfect circle into a more elliptical structure, or cause the sphere to "bulge" wherever the soft iron sources are located. Sophisticated software algorithms can compensate for this, but require a solid understanding of magnetic fields and how they are impacted by soft iron materials.

Compass Best Practices

- Place magnetometers in low magnetic interference areas
- Place soft-iron materials/magnetized items at least 10 mm away from a magnetometer
- Best locations for compass placement are stiffer PCB edges or corner locations
- Consider replacing soft-iron with low relative permeability materials such as:

  Copper $\mu r = 0.999994$

  Aluminum $\mu r = 1.000022$

  Silver $\mu r = 0.999974$

  Brass $\mu r = 1.000000$

  Gold $\mu r = 0.99996$

  Plastic   n/a

- Do not attempt to shield a compass from magnetic fields
  - High μr materials cause too much interference
  - Low μr materials won't help as they are invisible to the intended shielding purpose
- If shielding is required (e.g. radio frequency isolation) use low μr and low electrical resistance materials. Locate them about 10 mm away from the magnetometer
- Place magnetic sensors away from sources/traces with current fluctuations

Current Fluctuation (mA)	Recommended Distance from Trace (mm)
2	0.2
10	1
50	5
100	10
200	20

COMPASS – EXAMPLE OF APPLIED BEST PRACTICES
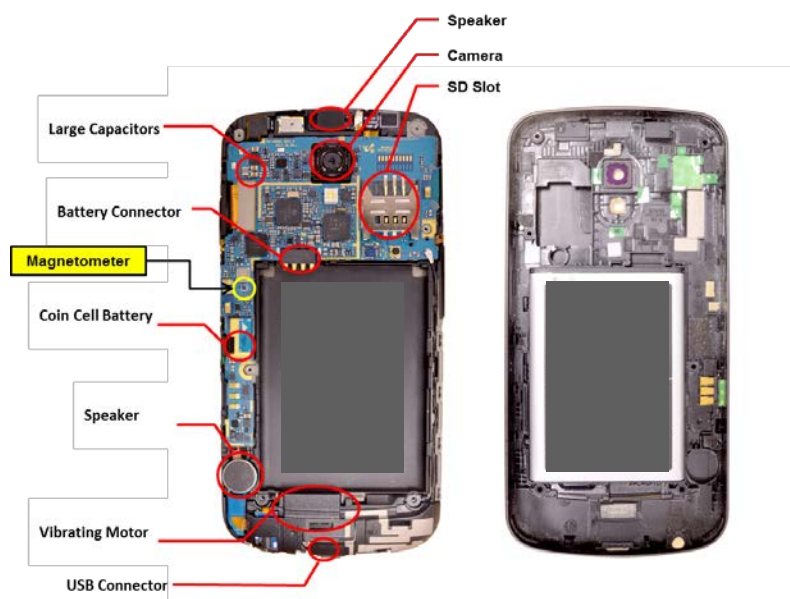
Typical Handset Components Causing Hard/Soft Iron Distortion

HEADING CALCULATION FOR COMPASS APPLICATIONS

A simple calculation of the earth's magnetic field can be obtained by calculating the angle of the X and Y axes as sensed by the magnetometer:

$$Heading\ Angle = \operatorname{atan}2(Y, X).$$

For applications, which require an accurate heading angle, this approach is not sufficient. Using this simplified method, the heading angle is highly dependent on the orientation of the MPU. As the Earth's magnetic field is sensed as a 3-dimensional vector, the simplified calculation is only accurate when the earth's field vector is aligned with the magnetometer's XY plane. This is not typically the case, as the earth field has a significant magnetic inclination (or magnetic dip), which depends on geography. For example, within the Continental United States, this inclination angle can vary between 55 and 75 degrees. Because of the high inclination angle, the heading output will be extremely sensitive to small changes in pitch and roll when rotating the device on a flat plane.

A much more accurate calculation includes rotating the sensed magnetic field to a horizontal plane, prior to computing the heading angle. For static measurements (when the device is stationary), an accelerometer reading is sufficient to estimate roll and pitch. During dynamic movements, the orientation output of motion-fused data is recommended.

Quaternion rotation may be applied to the magnetometer data, or calculation using Euler roll / pitch angles, using the following example:

$$X' = X * \cos(pitch) + Y * \sin(roll) * \sin(pitch) - Z * \cos(roll) * \sin(pitch)$$
$$Y' = Y * \cos(roll) + Z * \sin(roll)$$
$$Heading\ Angle' = \operatorname{atan}2(Y', X')$$

EVALUATION OF COMPASS PERFORMANCE

Once a compass is placed within its application (e.g. cell phone), the magnetic field can be evaluated through the analysis of sensor angular accuracy and noise.

The standard deviation of magnetometer data (also called noise) should be < 1 µT for raw data, so that digitally filtered data can be < 0.5 µT and reported at a high data rate. A noise level of 0.5 µT corresponds to a typical angle deviation or jitter of 0.5 degrees.

Angle accuracy can be measured by analyzing the heading angle of the sensor relative to its orientation. At precise rotations, the output and device orientation can be compared. Typical angle accuracy of ±2 degrees is reasonable for a calibrated magnetometer in consumer device applications.

Alternatively, a Helmholtz coil can provide a reference magnetic field signal for angle accuracy measurements, rather than rotating the device. A Helmholtz coil passes current through two coils of wire, placed at a precise distance equal to the radius of the two coils, as shown in the figure below. The magnetic field generated near the center of the coil has a uniform value over a significant volumetric space. By using a multi-axis Helmholtz coil, the generated field is fully controlled and can be rotated around a device precisely, independent of any environmental sources (e.g. steel frame of a building).
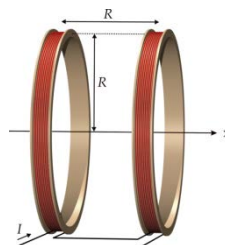
Example of Single Axis Helmholtz Coil

REVISION HISTORY

REVISION DATE	REV NUMBER	DESCRIPTION
08/27/2014	1.0	Initial Release

This information furnished by InvenSense is believed to be accurate and reliable. However, no responsibility is assumed by InvenSense for its use, or for any infringements of patents or other rights of third parties that may result from its use. Specifications are subject to change without notice. InvenSense reserves the right to make changes to this product, including its circuits and software, in order to improve its design and/or performance, without prior notice. InvenSense makes no warranties, neither expressed nor implied, regarding the information and specifications contained in this document. InvenSense assumes no responsibility for any claims or damages arising from information contained in this document, or from the use of products and services detailed therein. This includes, but is not limited to, claims or damages based on the infringement of patents, copyrights, mask work and/or other intellectual property rights.

Certain intellectual property owned by InvenSense and described in this document is patent protected. No license is granted by implication or otherwise under any patent or patent rights of InvenSense. This publication supersedes and replaces all information previously supplied. Trademarks that are registered trademarks are the property of their respective companies. InvenSense sensors should not be used or sold in the development, storage, production or utilization of any conventional or mass-destructive weapons or for any other weapons or life threatening applications, as well as in any other life critical applications such as medical equipment, transportation, aerospace and nuclear instruments, undersea equipment, power plant equipment, disaster prevention and crime prevention equipment.

©2014 InvenSense, Inc. All rights reserved. InvenSense, MotionTracking, MotionProcessing, MotionProcessor, MotionFusion, MotionApps, DMP, and the InvenSense logo are trademarks of InvenSense, Inc. Other company and product names may be trademarks of the respective companies with which they are associated.