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Introduction

Electronic devices contain many parts which can affect a magnetic sensor. When deciding the mounting position, it is necessary to consider the types of materials and the amount of current carried in proximity of the magnetic sensor.

Accuracy of an electronic compass depends upon getting clean geomagnetic data from the magnetic sensor output without errors caused by other magnetic elements. These errors need to be canceled by calibration or correction. This document explains magnetometer integration challenges from the mobile equipment point of view, and gives guidelines for the mounting position of the magnetic sensor.

Terms and Abbreviations

Low coercive force = eagerness for new magnetization changes

Saturation level = the level where a material's magnetization is no longer increasing

Residual magnetic flux density (remanence) = In magnetic hysteresis loops showing the magnetic characteristics of a material, the remanence is the value of the flux density remaining when an external field returns from a high value of saturation magnetization to 0. The remanence is also called the residual magnetization.

Remanence magnetic field = Br(T) is the current magnetization level status in Tesla

Integration highlights

The placement of a magnetometer in systems with disturbing magnetic field sources is a challenging task, because there can be many interactions within the confined mechanical volume. Magnetometer placement integration needs to be done at the same time as the mechanical and electronic design. If the magnetometer is simply "dropped" somewhere on the PWB without design considerations, there most certainly will be performance problems.

Distance versus magnetic field intensity

The effects of a magnetic field disturbance can be reduced by increasing the distance between it and the sensor. This simple phenomenon is frequently used to help place the magnetometer in a mobile device.

Example: Basic NdFeB (Br typ. 1.0T, magnet size 3x2x1.5mm) is magnetized through its longest side and measured along this axis.

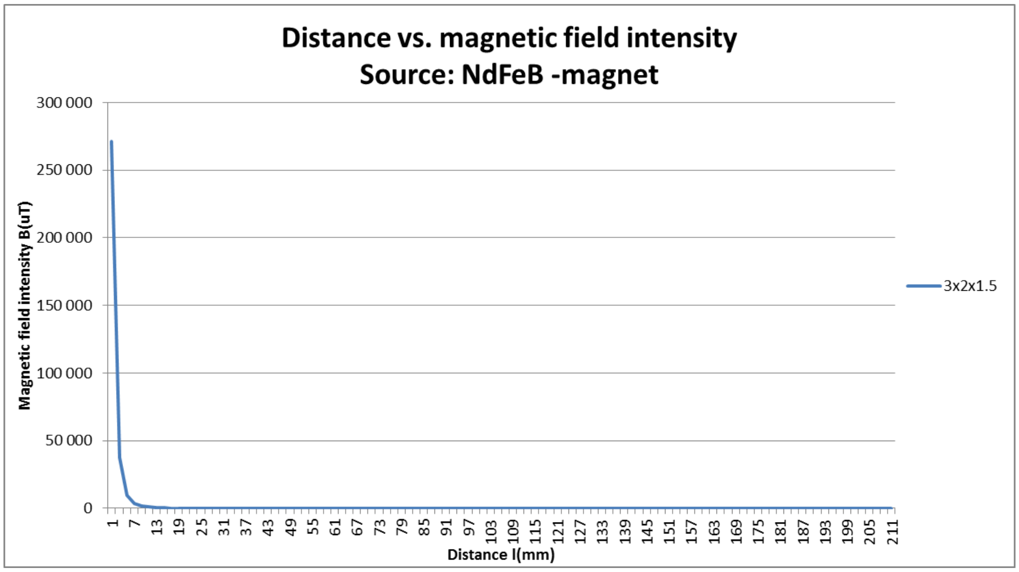

Figure 1: Large scale - Magnetic field intensity effect versus distance (Consider using a Log Scale for intensity)

Same magnet and setup, but scale of magnetic field intensity in diagram is reduced to earth's magnetic field total intensity level (~50µT).

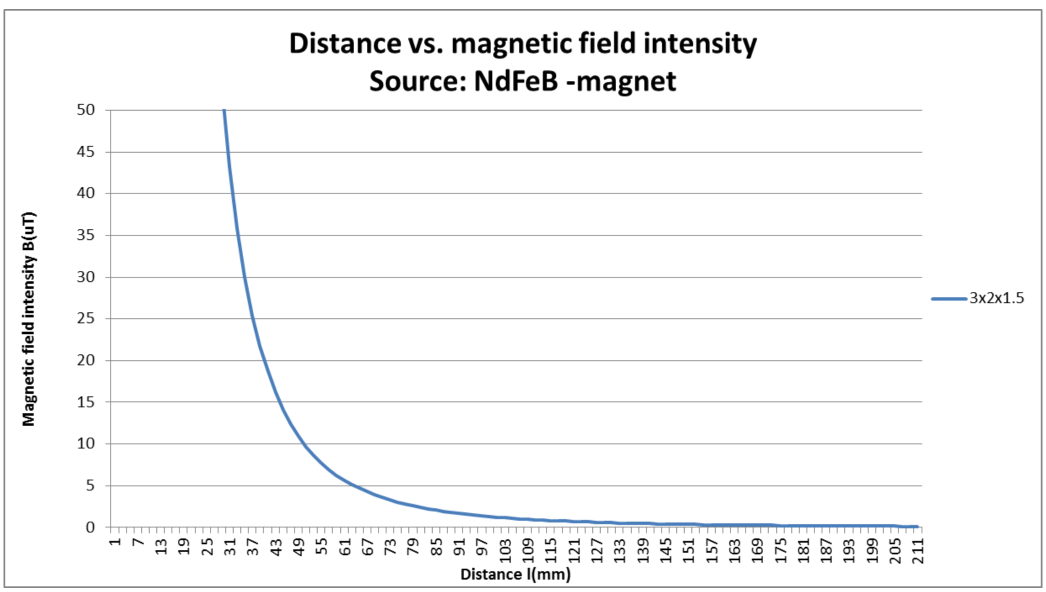

Figure 2: Reduced scale - Magnetic field intensity effect versus distance

Again same magnet and setup, but scale of magnetic field intensity in diagram is reduced to 2µT.

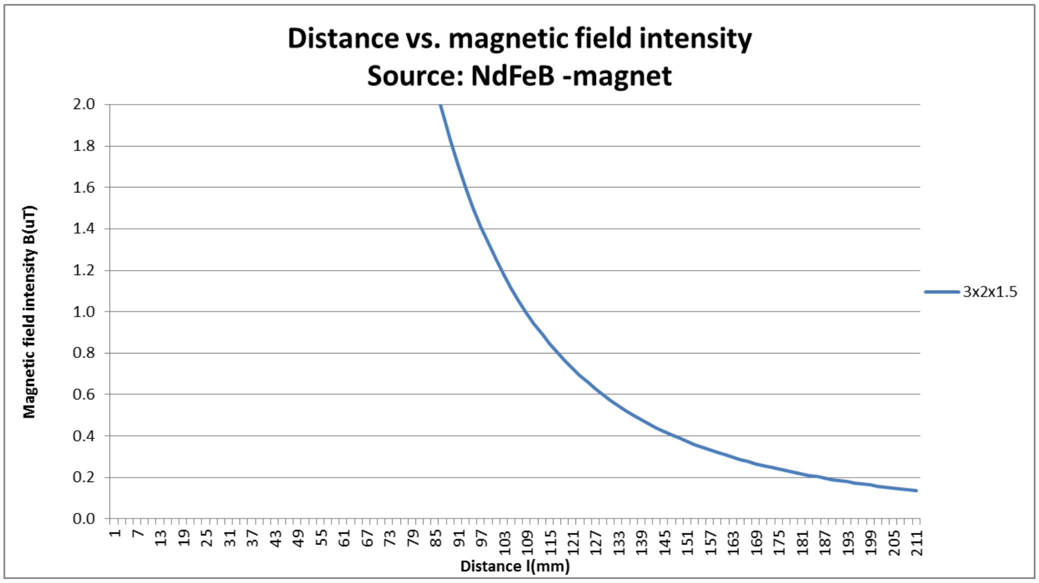

Figure 3: Very small scale - Magnetic field intensity effect versus distance

With this magnet along longest side axis, the magnetometer (resolution 0.146µT) will detect effect of this permanent magnet when the distance is smaller than 168mm (measured value is bigger than 2x the resolution step). If the measurement range is ±1200µT, without any other offset disturbing sources, the measurement range will be saturated when distance is smaller than 10.6mm.

Magnetic field disturbing sources by component types

Local magnetic field sources (inside of mobile devices) disturb the earth's magnetic field direction and intensity. Depending on disturbing sources, the effects can be separated into DC and AC type interference. The effect of all magnetic field sources is defined by the superposition principle, calculated together as vectors or axes components of magnetic field sources.

Typically, a high intensity local AC magnetic field will always and inexorably saturate a magnetometer's measurement. Lower intensity AC magnetic fields merely increase the noise seen in an application.

A high intensity local DC magnetic field will also saturate a magnetometer's measurement, but with lower intensity DC magnetic fields, it is possible to normalize offsets. But increasing the offset level in the auto-calibration / normalization process can cause performance problems.

The main target of magnetometer integration into mobile devices is:

- To find a place for the sensor where DC disturbing magnetic fields are minimal and do not exceed the design limits in the magnetometer point of view
- To find a place for the sensor where AC disturbing magnetic fields do not increase the measured noise level in magnetometer point of view

Targets include application environment effects inside of the mobile equipment and in all basic use cases of the end user.

Hard iron / Hard magnetic materials (Permanent magnets)

What is a hard iron or hard magnetic material?

It is a material with a high coercive force which has a large magnetic hysteresis and a small magnetic permeability. Typically, these are materials commonly referred to as permanent magnets. The magnetic fields of hard magnetic materials mix with the geomagnetic vector. See Figure 4 below:

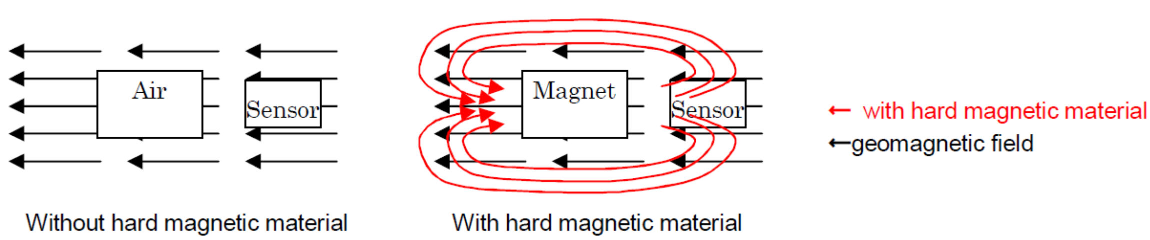

Figure 4: Effect of a hard magnetic material on the geomagnetic field

Mobile devices use several types of parts which includes permanent magnets:

- Speaker
- Vibras
- Motors, solenoids
- Camera–modules (voice coil motor type; for autofocus or image stabilization)
- Position detection magnets
- Latch magnets (cover wearing, hinge latches)

The effects of a permanent magnet are easier to estimate and predict because the material type, shape, and magnetic field direction and intensity are known. A permanent magnet's statistical behavior is well known. The effects inside a single mobile device are permanent in direction and intensity, and can be compensated.

Permanent magnetic material types typically used in mobile equipment are:

- Neodymium (NdFeB)
    - Br (T) ranges from 1.0 to 1.5, variation factor 0.8 - 1.1 (in typical commercial grades)
- Samarium Cobalt (SmCo)
    - Br (T) ranges from 0.9 to 1.2, variation factor 0.8 - 1.1 (in typical commercial grades)
- Hard Ferrite
    - Br (T) ranges from 0.3 to 0.5, variation factor 0.5 - 1.2 (in typical commercial grades)
- Plastic Ponded
    - Br (T) ranges from 0.5 to 0.8, variation factor 0.5 - 1.2 (typically commercial grades)

Practically, the strength of a magnet is dependent on the material/technology used and the volume (x,y,z). Thinner magnets, on the order of <1.0mm, are 10%-15% weaker.

Examples of permanent magnetic field effects

The table below explains examples of how far components must be placed from the magnetometer so that their effect is reasonable from a design point of view. The table shows the distance between a magnetic field source and the magnetometer in order to create an offset disturbance of ±50µT or ±100µT. Distance values are for typical parts. Every component type must be characterized and modeled separately.

	Distance mm/50µT	Distance mm/100µT	Materials	Note
IHF speaker	> 37	> 30	SmCo NdFeB	Typically Z -axis oriented but new generations have also horizontal orientations
Earpiece	> 28	> 23	SmCo	Typically Z-axis oriented
Vibra, cylinder 10xD4mm	> 20	> 16	SmCo NdFeB	Magnetic field depends on rotator’s position
Vibra, coin 10x10x3mm	> 24	> 19	NdFeB	
Camera, VCM module	> 12	> 9	SmCo	No clear magnetic field direction
Magnet 3x4x1.3mm	> 28	> 22	NdFeB	
Latch magnet 10x5x1mm	> 29	> 23	Hard Ferrite	
Motor 12xD5mm	> 24	> 19	SmCo NdFeB	Magnetic field depends on rotator’s position

Table 1: Permanent magnet parts effect versus distance

The fields produced by permanent magnets are seen as a permanent part of the offset. This is a stable offset position in a single mobile device, and the variation within the full population of devices is also well known.

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Soft magnetic materials / Low coercive materials

What is a soft magnetic material?

It is a material with a low coercive force which has a small magnetic hysteresis and a large magnetic permeability. Materials with a large magnetic permeability (µ) focus and distort the geomagnetic vector.

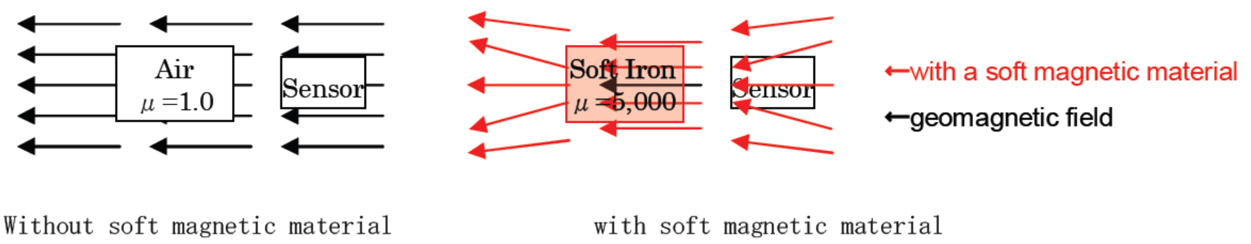

Figure 5: Effect of a soft magnetic material on the geomagnetic field

Low coercive ferromagnetic materials can rapidly change their magnetization status under the influence of an external magnetic field. This is always challenging from the auto-calibration/normalization algorithm point of view. Practically, after integration, only the remanence Br (T) level after saturation can be detected. The material's magnetic field status is not homogenous; it can change in a small area of a sheet of ferromagnetic materials. Also, forming actions such as bending, cutting and welding, can change the local magnetic field status and cause large local magnetic field changes.

Generally, if any material includes ferromagnetic parts (typically Fe, Ni, Co), it affects the direction and intensity of earth's magnetic field and other magnetic field sources. The level of these effects and changes depend on the source characteristics and distance.

Typical low coercive force ferromagnetic materials used inside of mobile devices are;

- Stainless Steel (SS) construction parts
- Carbon steel (CS) construction parts, screws, housing
- Alloys which include iron or/and nickel like German Silver
- Plating layer which includes ferromagnetic materials
- Sintered Ferrite composition (ferrite coils)

The effect of low coercive force materials is not predictable over time, because they can, for example, become magnetized). Only the saturation limit ranges of the materials can be known, and therefore, the design needs to take these saturation limits into account.

Example of low coercive magnetic force effects

The table below explains examples of how far components must be placed from the magnetometer so that their effect is reasonable from a design point of view. The table shows the distance between a magnetic field source and the magnetometer in order to create an offset disturbance of ±50µT or ±100µT. Distance values are for typical parts. The table below has saturation limit values of some typical materials. These values are advisory levels only since the variation of ferromagnetic saturation levels is wide.

	Br max. m(T)	Distance mm/50µT	Distance mm/100µT	Notes
ASTM A307 Steel (CS)	30-50	> 14	> 11.5	Sheets, screws, nuts, housings Size 10x10x0.3mm
Springs (CS)	> 60	> 15	> 12	High formed steel Size 10x10x0.3mm
SUS301, 50%H (SS)	10-30	>12	>10	Sheet, size 10x10x0.3mm
SUS301, 75%H (SS)	30-40	>13	>11	Sheet Most used high strength SS for construction
SUS304, 50%H (SS)	5-10	> 9	> 7.5	Sheet, size 10x10x0.3mm
SUS304, 75%H (SS)	10-15	> 10	> 8.5	Sheet, size 10x10x0.3mm
SUS305, 50%H (SS)	2-8	> 8.5	> 7.5	Sheet, size 10x10x0.3mm
SUS305, 75%H (SS)	5-10	> 9	> 8	Sheet, size 10x10x0.3mm
SUS316 (SS)	2-5	> 7.5	> 6.5	Sheet, size 10x10x0.3mm
Copper alloys CuNi18Sn	1-4	> 7	> 6.5	Sheet as RF shields, size 10x10x0.3mm
German Silver	1-4	> 7	> 6.5	Sheet as RF shields, size 10x10x0.3mm
Ni layers under gold	< 5	> 0.6-1.0	> 0.5-0.9	Size 0.5x0.5x0.05 in PWBs and substrates
Fe, Ni, Cr or Co in layers	< 2-5	> 0.8-1.2	> 0.6-1.1	Coatings generally, size 1x1x0.05mm
Ferrites	1-20	> 12	> 10	10x10x1mm Depends on use cases

Table 2: Low coercive force materials effects versus distance

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For low coercive force materials, the remanence (Br max.) parameter changes per supplier and production batch in same standardized material. Magnetic field properties of ferromagnetic materials are not commonly measured per batch by manufacturer or forming manufacturers.

Currents in PWB traces and wires

Electric current effect is small but it must be taken into account when current traces are near of magnetometer.

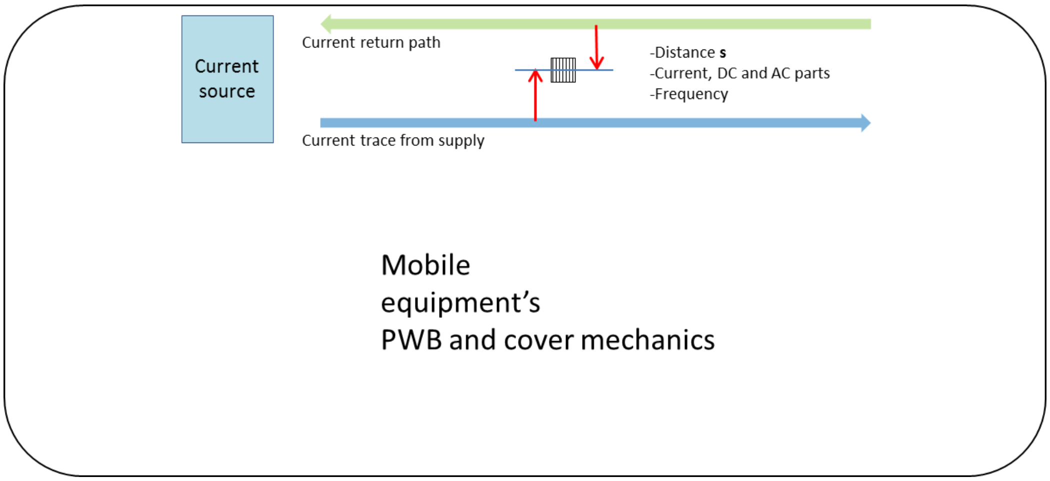

Figure 6: Supply current traces placement

Currents in traces of PWB near magnetometer can be calculated as one wire effect. Depending on the construction, the return path current's effect must be taken into account. A DC current's effect on the magnetometer is an offset shift, which can be taken into account by the auto-calibration / normalization algorithm. If the current is acting in an AC manner (i.e. time varying), then the effect on the magnetometer is noise and oscillations related to the nature of current waveforms.

Calculated distances for electrical current traces are defined in the table below. Real environment will need a margin of 3 - 5mm more.

Current mA	Distance mm/50µT	Distance mm/100µT	Notes
100	>0.4	>0.2	
300	>1.2	>0.6	MCU, display and illumination
1000	>4.0	>2.0	3G, charging current
3000	>12.0	>6.0	2G /GSM PA peak current

Table 3: Electrical Current effects versus distance

Highest current traces are coming from/to;

- RF PAs
- Charging unit/ battery connector, from wired or wireless chargers
- Display module and light illumination units
- Local DC/DC converters

Magnetic fields from electrical current can be designed to cancel each other out by placing the output current and return current paths close to each other.

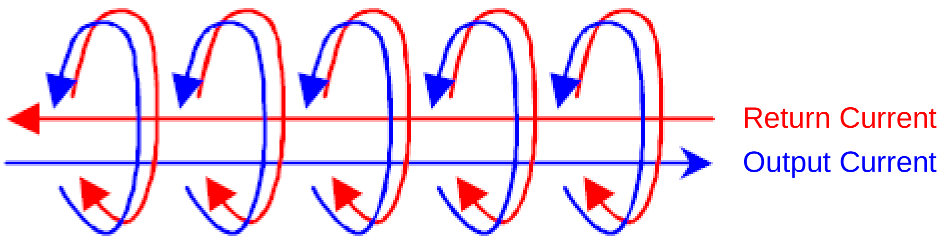

Figure 7: Canceling or minimizing magnetic fields from currents

Internal Peripherals

Coils

Large coils are typically used for power management, such as DC/DC converters. These kinds of coils are a special case because:

- big current spikes can exist through the coil windings.
- The coil's core is a ferrite material, which has volatile magnetic field properties and high Br(T) value
  - During use, when control turns off the coil, the last remanence position defines the current status of magnetic field in ferrite material.

NFC antenna

NFC antennae are used for short range 2-way communication with relative low frequency. The loop concentrator material is typically ferrite. The main problem is the volume of ferrite materials in close proximity to the magnetometer. The magnetic field produced by NFC current is not a significant problem.

Inductive battery recharging

Wireless (or inductive) charging (example: Qi standard) is transferring energy to mobile devices. The receiver inside of the mobile device has large areas of ferrite with a wound transfer coil. The charging technology and its use create a disturbing level of magnetic field. When control turns off the receiver coil, the last magnetized position defines status of the magnetic field inside the ferrite material.

This technology is new and has not matured, however, and there are integration problems and considerations with inductive technology chargers and magnetometers.

Most challenging components and parts

The most challenging aspects of integrating a magnetic sensor into a mobile device are listed below:

1. Construction or decorating steel sheets and parts need physical clearance around the magnetometer in every direction:
    - Openings in sheets to allow this can decrease mechanical strength.
    - Ferromagnetic material effects are not able to be predicted, and openings must be designed with low coercive force materials in mind.
    - Forming actions such as bending, cutting and welding will increase local magnetic field source effect.
    - Thin material is typically more magnetic, depending on the material type and hardness.
2. IHF and earpiece speakers:
    - The mobile device's integration area is small and the speaker needs some distance from the magnetometer.
    - Permanent magnet inside the speaker is big and powerful.
    - Audio signal current can have a small noisy effect, when peak current is near 1A.
3. Screws, nuts and other carbon steel material parts:
    - Materials can be magnetized and act as a permanent magnet.
4. Ferrite coils passing AC current. Typically used in DC/DC converters for power management purposes:
    - Remanence Br(T) can be huge in the core material, even when current switched off.
    - AC current will create magnetic field noise.
5. Vibras, solenoids and motors:
    - Steady effect is relatively small but it depends on rotor position.
    - When rotor is moving, component produces high magnetic field spikes which are seen as noise and extra oscillations in the magnetometer's output.
6. Internal peripherals, NFC antenna and wireless charger;
    - Strong local magnetic field spots from ferrite materials.
7. Electrical components which includes ferromagnetic material(s)
    - Ceramic capacitors (by some manufacturers) can contain nickel.

Components placement effect (example):

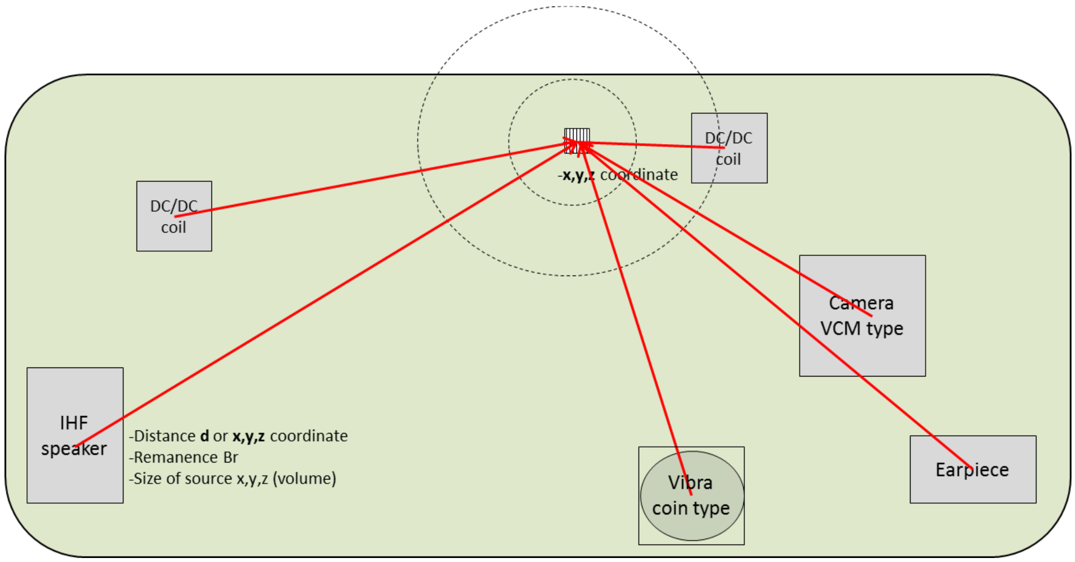

Figure 8: Component placement

Ferromagnetic materials (example):

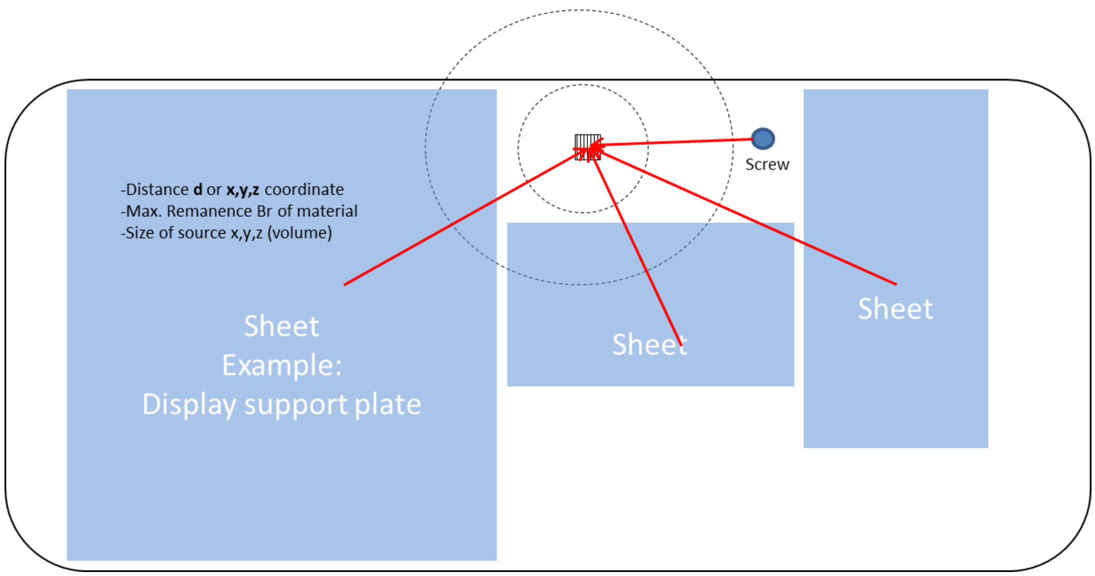

Figure 9: Ferromagnetic parts placement

Magnetometer placement integration at the same time as mechanical and electronic design is mandatory. If magnetometer is "dropped" somewhere in PWB without design considerations, there will likely be performance problems.

Most challenging areas

Areas which make disturbances in magnetic fields:

1. Cellular antenna area(s)
   - Current produced by a magnetic field near the antenna is a problem and can cause noise and oscillations in the magnetic field.
   - High power level RF signals are problematic if the magnetometer is under the cellular antenna area.
2. RF and baseband shields near magnetometer integration areas
   - Shielding materials can contain too much nickel, which creates soft iron (magnetic) effects (producing ellipsoid behavior).
   - Typically, a mobile device's PWB is almost completely covered by different shield cans on both sides of the board.
3. Battery connector area and traces, battery current rail area on top of battery, and RF PA supply traces
   - DC and AC–type current effects in the magnetic field
4. Nickel under Gold in PWB and component's substrates near the magnetometer
   - The effect is small, but Au-Ni layers can be very close to the magnetometer's most sensitive regions.
5. Large areas of ferromagnetic material coatings near the magnetometer
   - Nickel based plating/coating materials have soft iron effect on measurement performance.

Helpful Methods for Board Design

In the course of the design process, components and current loads can change from the initial design. In order to minimize risks during board design, the following steps are recommended:

1. Prepare multiple candidates of different magnetometer mounting positions

Maintain a number of candidate mounting positions right up until the final mass production prototype. If your first candidate fails, then you have the option to use another position without a major modification and re-test effort

2. Mount the sensor on a daughter board or flexible board instead of the main board.

Both of these methods will give more freedom to considering and changing the mounting location.

Kionix has tools to assist customers in characterizing the magnetic environment inside their mobile device and to help place the magnetometer in the optimal location. Contact your local Kionix sales office for more information.

The Kionix Advantage

- A diverse product line of low-power, high-performance accelerometers, gyroscopes, and 6-axis combination sensors.
- Comprehensive software libraries, including sensor fusion software, that support a full range of sensor combinations, operating systems and hardware platforms.
- Unmatched application development tools, firmware and reference design development support.
- A global presence with sales offices across the U.S., in Europe, and throughout Asia.
- A partnership approach that begins with early development and extends way beyond the purchase order, culminating in our customer's delivery of their product to market.
- World-class manufacturing capacity and capability that enables us to meet volume production on stringent deadlines.

About Kionix

Kionix, Inc. is a global MEMS inertial sensor manufacturer based in Ithaca, NY, USA. Kionix offers high-performance, low-power accelerometers, gyroscopes, and 6-axis combination sensors plus comprehensive software libraries that support a full range of sensor combinations, operating systems and hardware platforms. Leading consumer, automotive, health and fitness and industrial companies worldwide use Kionix sensors and total system solutions to enable motion-based functionality in their products.

Kionix utilizes a deep-silicon, proprietary MEMS technology known as plasma micromachining for its high-volume production. This technology enables Kionix to produce MEMS products that are unmatched in performance and manufacturing cost. As such, the Company holds an extensive portfolio of licensed and internally-developed intellectual property.

Kionix was acquired by ROHM Co., Ltd. of Japan on November 16, 2009. Kionix is able to leverage ROHM's resources as a leading semiconductor company in order to advance its technology, sustain its growth while reducing costs, and expand its global reach through an established and thriving international customer base. The Company continues to operate as Kionix and its products continue to be produced primarily at its headquarters in Ithaca, New York, USA. Kionix's commitment to customers in sales, development support, integration expertise, and pricing remains paramount.

Today, Kionix continues to respond to growing market demand for increased product applications, while creating new product opportunities in industries as diverse as automotive, consumer electronics, biotechnology, wireless communications, and pharmaceutical research.

For a product catalog, please visit: http://www.kionix.com/