# Input for Magnetometer Placement Simulations

## Introduction

Simulations of the magnetic field environment to provide magnetometer part placement recommendations need considerable technical information to assist the process. Magneto-static and magnetic noise information of the materials and magnetic field sources need to be collected from the design candidate's 3D geometry, materials, and functional proposals. With this information, magneto-static simulations can be done to guide the optimal part placement in a system.

36 Thornwood Dr. – Ithaca, NY 14850
tel: 607-257-1080 – fax:607-257-1146
www.kionix.com - info@kionix.com

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## Goals for magnetic field source information collection

Every strong magnetic field source near the magnetometer will need a simple magnetic field source model because the effects of all magnetic field sources sum together. A magnetic field source is considered significant (too strong and too close) if its effect is 4-5x higher than noise floor level of the magnetometer measurement signal.

Adequate levels of information will help review the design candidate's goodness and set appropriate expectations of application performance. Results of this information collection are used for the magneto-static simulations of the design candidate. These simulations will assist the design during the placement of the mechanical devices and the creation of the PWB layout.

Goals:

1. Find the maximum magnetic field static disturbance effects on the magnetometer (x, y, z) measurements when the PWB is fully populated.
2. Find the variation range of magnetic field static disturbances seen by the magnetometer (x, y, z) measurements when the PWB is fully populated.
3. Find magnetic field noise range seen by the magnetometer (x, y, z) measurements under different use cases.

## Terms, parameters and Abbreviations

- **Coercive force** = a measure of the magnetization of a ferromagnetic material as expressed by the external magnetic field strength necessary to demagnetize it
- **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 the 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
- **Relative permeability** = μr, which tells the relative magnetization capability of material
- **PWB** = Printed Wiring Board, where magnetometer is placed
- **3D** = Three Dimensional
- **SS** = Stainless Steel

## Scope of information request and details

The scope of information needed encompasses the main design area and also any peripherals which are close to or connected to the main design and changed by user actions. The design candidate should be the detailed design version which is under investigation. If any changes are done to the design candidate after this review, then a review of the magneto-static design must be performed again with the revised information.

- The entire integration/design area must be included for the magneto-static review:

  - Construction and cover mechanics
    - Fixed structures
    - Moving structures and their positions
    - Peripherals which are attached to the main design
  - Electrical and mechanical components
  - Electrical currents
  - Special uses cases: such as charging, audio, and imaging (anything which can change magnetic field environment locally in the design)

- Magnetic field noise information is collected from electric current properties:

  - Wires and coils/solenoids with AC parts separately

- Out of scope parameters and actions for the magneto-static review:

  - Magnetic field environments outside of the design (except the Earth's magnetic field)
  - User actions which are not related to design itself
    - High frequency and fast changes in magnetic field: magneto-static review is only for static (DC-like) magnetic fields. Fast changing magnetic fields will have an effect on the behavior of the magnetic field sensing, however, higher frequency magnetic field changes are assumed to act as noise on the magnetometer measurements. Information related to magnetic field noise is collected separately.

## Main factors

### Integration area

The integration area consists of magnetic field sources on the PWB, construction mechanisms with ferromagnetic material parts, peripherals and uses cases/application related changes in local magnetic field.

- Magnetometer placement (as a reference position) on PWB is selected according available information about magnetic field sources **OR** placement of magnetic field sources is done according to the requested placement of magnetometer component.
- If a magnetic field source is inside of a moving part, reasonable moving part positions must be taken into account separately.

### Co-ordinate system

A co-ordinate system must be selected and agreed upon in order to perform the magneto-static simulation.

- The directions and polarity of axes of the co-ordinate system must be selected before starting information collection.
  - The same co-ordinate system that is used for the mechanical design is a reasonable system to use.
- All geometric dimensions are given in co-ordinate axes (x, y, z) values
- The co-ordinate system is relative to magnetometer's center of mass position.

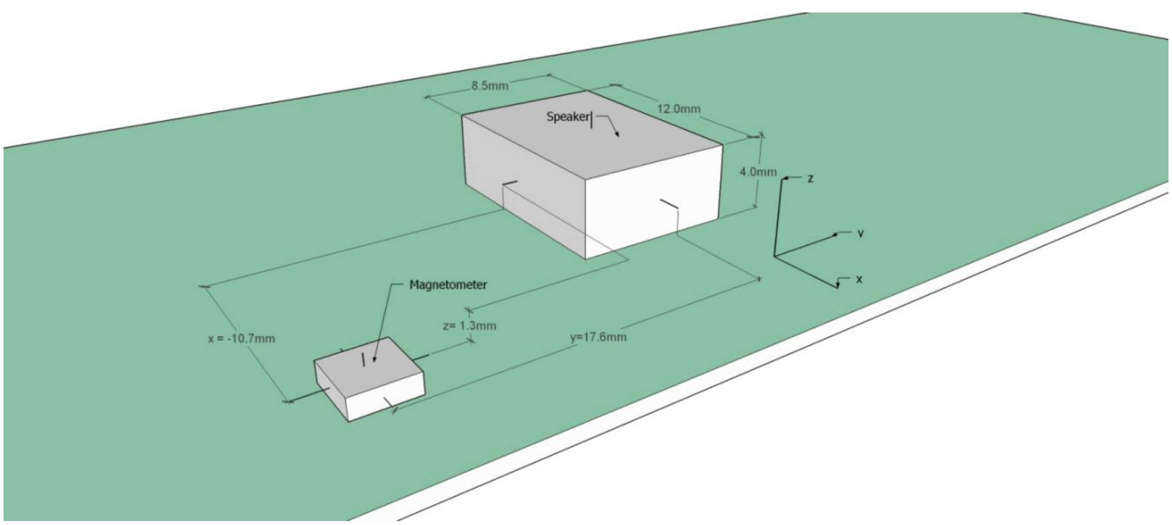


Figure 1: Dimensions in co-ordinate system (example PWB)

An easy way to define and report distance values between the magnetometer component and the disturbing magnetic field source is from center of mass to center of mass.

- Distance and dimension values: millimeters, inches, or mils
- Distance and dimension values are reported in axes values (x,y,z) with tolerance information
- 0.1mm dimension definition accuracy is enough when the distance is more than 4mm from magnetometer edge to disturbing element edge
    - placement dimension accuracy and tolerance variation become more important when the disturbing source is closer to the magnetometer

**Magnetometer**

A magnetometer component is placed on a PWB – either a rigid main board or a semi-rigid (flex) board. The co-ordinates of the magnetometer are not always the same as the design co-ordinates. This must be taken into account when merging different information sources for the simulation.
One easy method for merging the different 3D information systems together is to set the magnetometer's center of mass (0.0 mm, 0.0 mm, 0.0 mm) as the reference position and review magnetic field sources /disturbing elements relative to this reference.

- The sensor's sensitive parts are typically not located at the center of mass. However, the center of mass is a good approximation for the sensor functionality estimation.
    - Exceptions are some capacitor components which have nickel in layers and the NiAu layers of the PWB

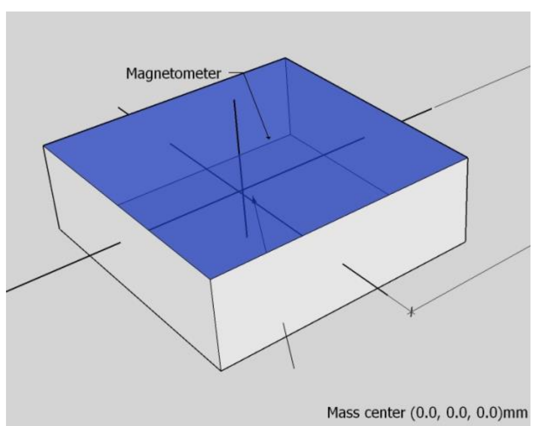


Figure 2: Magnetometer position in reference mass center (0.0 mm, 0.0 mm, 0.0 mm)

## Magnetic field sources / disturbing elements

All significant magnetic field sources inside the integration area must be taking into account.

- Dimension and tolerance is informed as x, y, z axes specified values, according setup position in integration
- Magnetic field source /disturbing element has dedicated magnetic model which defines:
  - Static magnetic field properties of model's volume
  - Direction and polarity of magnetic field (magnetization)
  - Magnetic noise portion is informed separately in own model entry
- Magnetic field source /disturbing element dimensions definition accuracy; 0.1mm accuracy is enough when closest distance is more than 4mm from magnetometer edge to disturbing element edge
  - disturbing elements dimension and distance variation becomes more important when disturbing source is more closer to magnetometer
- Model shape
  - For other than current related magnetic field source, simplest way to define disturbing source model is rectangular tile /cubic shape according maximum outlines dimensions
  - Current wire and coils uses cylindrical model

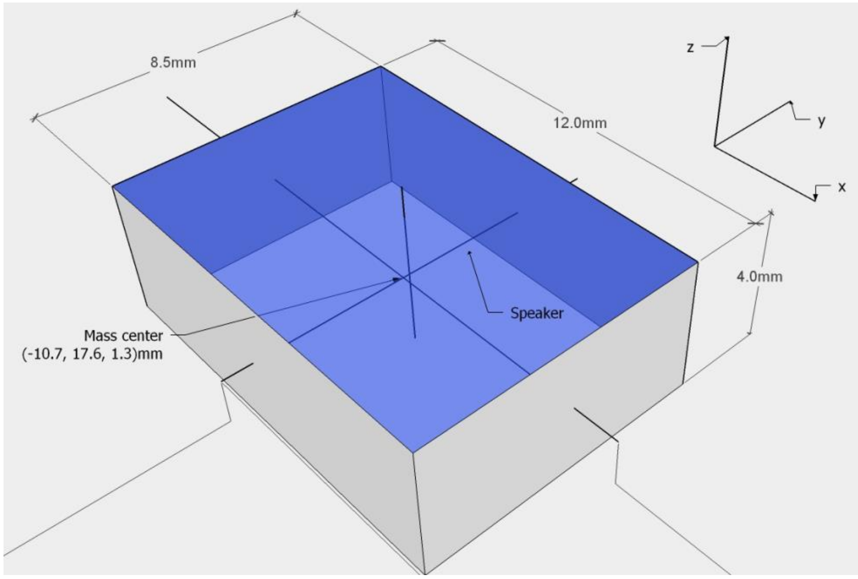


Figure 3: Magnetic field source /disturbing element (example)

- Magnetic field source magnetic field polarity and direction defined as vector of field axes components (x, y, z). All magnetic field sources' axis components (x, y, z) can be calculated together with superposition method

## Input information

Collected input information for magneto-static review includes:

- Geometry of components and any constructions which act as magnetic field sources
- Magnetic properties of the materials of these components and constructions
- Current-related magnetic field sources
- Detailed geometry of magnetic field sources relative to the magnetometer component.

Most of requested information is available during the design process.

### Design and Integration Documents

All available and detailed documentation of the design candidate will help the magneto-static design, review, and integration. If some detailed information is not available, default or assumed values can be used.

- Detailed information of the mechanical construction helps to determine the dimensions of possible disturbing parts like ferromagnetic structures
  - 2D dimensional drawings of constructions near the magnetometer
    - dimensions and tolerances (parts and positions)
  - 2D cross section through sensor part position (sections of axes pairs; xy, xz and yz) when available
  - 3D player/viewer files of construction (example 3DXML format from CATIA), these files are helpful for viewing details inside of structures
- Layout and construction information that define the positions of magnetometer and disturbing components. Also electrical trace positions can be defined for review.
  - PWB design
    - all layer images near magnetometer
    - PWB build-up is helpful also as this documents helps the review of items inside the board, and also includes geometric information about the PWB
    - Current traces near magnetometer
  - Magnetic field source /disturbing element as components in PWB and construction
    - size, position, and tolerances

## Material properties

For magneto-static review, only materials which affect the static magnetic field are important. Components and their material properties are combined to create magnetic field source models.

## Permanent magnets

- Permanent magnet materials like NdFeB (Neodymium), SmCo (Samarium Cobalt), AlNiCo, Hard ferrite, Plastic bonded.
    - Permanent magnet alone: modeled as a rectangular or cylindrical shape
    - Components which have permanent magnet part(s) in construction: modeled with pure permanent magnet part and dimensions of it or full construction including permanent magnet with component dimensions. Both cases, remanence Br(T) is related to volume of selected dimensions.
- Parameters and other information for design and review;
    - Remanence Br(T) value is defined as typical, minimum and maximum values of full population variation
    - Dimensions of magnet: size and tolerances
    - If very thin magnet body (<1mm), coating material is needed to take into account for magnetic field source definition
    - Permanent magnet has steady magnetization directions and polarity, regarding specification
    - Informed magnetization direction (angle) variation can be significant <10% with all permanent magnet shapes

## Low coercive materials which can act as magnetic field sources

- Ferromagnetic materials (mostly Fe and Ni alloys) where the magnetic properties produce measurable static effects on the magnetometer's offset values under any conditions or use cases are taken into account
    - Ferromagnetic parts, compounds, and alloys
    - Low coercive material is modeled as rectangular or cylindrical in shape. One practical way is to divide bigger parts into smaller sub parts and review each sub part, example 3x3mm portions
    - Thin ferromagnetic layers and coatings are modeled as smaller portions of material volumes
    - Typically low coercive material part (example stainless steel) do not have homogenous magnetic field remanence throughout the sheet, and this affects larger sheet construction parts

- Ferromagnetic materials which have locally increased magnetic field effect properties related to forming, cutting or bending of material during manufacturing
- Generally heat and force to material changes magnetic field properties, more or less increasing it near action center locally. Therefore punch of ferromagnetic metal sheet will increase magnetic field source in edge after action because punching increases heat locally. Same cutting task with waterjet has no effect.
- This kind of magnetic field spots and area portions can be modeled separately, typically magnetic field remanence increases at least 2-3x in action area
- Low-coercive material has huge variations related to supplier and batch. Typically magnetic field properties are informed in very general form for material type and grade
- Parameters and other information for design and review;
- Br(T) max
- Practically only ±Br(T) max value can be estimated, so positive and negative values are used for modeling
- Momentary value of Br and magnetization direction is related to material and magnetization history, it is not predictable value
- μr = relative permeability (factor), this is supportive parameter
- Parameter tells how eager material is to magnetize
- Value of parameter can be between 1 and 100000, for stainless steel it is range of 1.02 to 10 (typically)
- Dimensions of magnetic field source; size and tolerances
- Practically low coercive materials has no permanent magnetization direction and polarity, because external magnetic field disturbances changes them rapidly
- During design and review action, widest effects of disturbance from magnetic field source direction and polarity can be estimated and use this information only for review. For better view of effects, other main directions in co-ordinate system and polarity can be also reviewed

## Current-related magnetic field sources

Magnetic models for wire traces and coil systems are different because coils behave more like solenoid systems, with or without core materials. The core element of coil can be modeled separately as low coercive material component. Stray magnetic fields from coils/solenoids can be estimated.

Origin of current related magnetic field sources are:
- Wire traces in PWB
- Coil type components in design
  - Speakers and Solenoids
  - DC/DC converters and wireless chargers
  - Special antennas

Current related magnetic field sources have no initial remanence magnetization, if no core material inside of coil. The core and its material can be modeled separately as a low coercive material.
- Wire traces – Parameters and other information for design and review:
  - Distance and tolerances from magnetometer center of mass to wire center measured perpendicularly
  - Trace length of wire which generates noise greater than 4-5x the magnetometer measurement noise floor
  - DC and AC portions of the current are separated and run in different models
  - Also the return current path in the PWB (ground plane) is also a "trace" which must be taken into account
- Coils /solenoids – Parameters and other information for design and review:
  - Dimensions, position and tolerances of coil's cylinder center
  - The coil is modeled with or without core material
  - DC and AC portions of the current are separated and run in different models

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## Appendix 1: List of input parameters

This list is an example for input information collection. Because the list has information about different magnetic field sources, it is not necessary to fill in all the information for each model type. For example, for a wire conducting currents near the magnetometer, only those rows marked with an "X" in the Wire model column need to be filled in. Tolerance information of dimensions and distances can be merged together for simplicity reasons.

Every magnetic field source has own information collection entry. When needed, bigger compound components can be divided to smaller parts. The best result can be achieved when the magnetic field sources near magnetometer are modeled as smaller parts; this increases the accuracy of the review.

| Input parameter name | Definition | Perm. magnet model | Low coercive part model | Wire model | Coil / solenoid model | Note |
|---|---|---|---|---|---|---|
| Name of magnetic field source | only for information | x | x | x | x | |
| Type of magnetic field source model | from design or datasheet docs | x | x | x | x | Choose one type of model |
| Material | from design or datasheet docs | x | x | | | Element, alloy or partial ferromagnetic material |
| Grade or hardness of material | from design or datasheet docs | x | x | | | as forming factor |
| Shape of magnetic field source | from design or datasheet docs | x | x | 1 wire | solenoid | rectangular or cylindrical |
| Dimension of x axis (typ) | outline of magnetic field source | x | x | x | x | |
| Dimension of y axis (typ) | outline of magnetic field source | x | x | | x | |
| Dimension of z axis (typ) | outline of magnetic field source | x | x | | x | for cylindrical type; main axis |
| Tolerance of dimension x (min) | from design or datasheet docs | x | x | x | x | |
| Tolerance of dimension y (min) | from design or datasheet docs | x | x | | x | |
| Tolerance of dimension z (min) | from design or datasheet docs | x | x | | x | |
| Tolerance of dimension x (max) | from design or datasheet docs | x | x | x | x | |
| Tolerance of dimension y (max) | from design or datasheet docs | x | x | | x | |
| Tolerance of dimension z (max) | from design or datasheet docs | x | x | | x | |
| Distance of x axis (typ) | axis component distance | x | x | x | x | mass center x to magnetometer's mass center |
| Distance of y axis (typ) | axis component distance | x | x | | x | mass center y to magnetometer's mass center |
| Distance of z axis (typ) | axis component distance | x | x | | x | mass center z to magnetometer's mass center |
| Tolerance of distance x (min) | manufacturing variation | x | x | x | x | in PWB |
| Tolerance of distance y (min) | manufacturing variation | x | x | | x | in PWB |
| Tolerance of distance z (min) | manufacturing variation | x | x | | x | in PWB |
| Tolerance of distance x (max) | manufacturing variation | x | x | x | x | in PWB |
| Tolerance of distance y (max) | manufacturing variation | x | x | | x | in PWB |
| Tolerance of distance z (max) | manufacturing variation | x | x | | x | in PWB |
| Br(mT) x (typ) | residual magnetization | x | x | | | for superposition (x,y,z) |
| Br(mT) y (typ) | residual magnetization | x | x | | | |
| Br(mT) z (typ) | residual magnetization | x | x | | | |
| Br(mT) x (min) | residual magnetic field variation | x | x | | | |
| Br(mT) y (min) | residual magnetic field | x | x | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | variation | | | | | |
| Br(mT) z (min) | residual magnetic field variation | x | x | | | |
| Br(mT) x (max) | residual magnetic field variation | x | x | | | |
| Br(mT) y (max) | residual magnetic field variation | x | x | | | |
| Br(mT) z (max) | residual magnetic field variation | x | x | | | |
| DC Current(A) steady portion | | | | x | x | |
| AC Current(A) peak to peak portion | | | | x | x | as magnetic noise |
| Loop count for coil/solenoid | | | | | x | |
| | | | | | | |

**Table 1: Input information from one source**

## Appendix 2: List of magnetic field sources

The most common magnetic field sources in mobile electronics are listed in the table below:

| Magnetic field source | What, why, where | Note |
|---|---|---|
| Permanent magnet parts | Including NdFeB, AlNiCo, SmCo, hard ferrite, Bonded Plastic | |
| Speaker | Earpiece, IHF speaker | vertical or horizontal (in PWB) magnetization |
| Vibrator | Cylinder or coin types are most common | Includes moving parts and produces magnetic field spikes |
| Latch magnet | Construction magnet, keeps two part together with magnetic force | system includes always opposite part which typically is higher permeability carbon steel part |
| Switch magnet | Position magnet which ensures accurate contactless switching action with magnetic switch component | Flip or slide open/close constructions (moving construction parts) |
| Motor or actuator | Micromotor and VCM constructions; example camera | Wide and amorphous magnetic field shapes because multiple pole magnet constructions Includes moving parts and produces magnetic field spikes |
| | | |
| | | |
| Low-coercive material parts | | |
| Carbon Steel (CS) | Stronger construction material; example screws, housings | Magnetic field property variation is not well managed and informed |
| Stainless Steel (SS) | Lighter construction sheet material, widely used | Magnetic field property variation is not well managed and informed |
| Other NiFe based alloys | Special usages | |
| Copper-Nickel alloys | Shielding material for RF and BB sections | Magnetic field property variation is not well managed and informed |
| | | |
| Layers/coatings | Component or surfaces | Quite thin and pure materials as Fe, Ni layers Some passive components like capacitors have nickel layers Most typical hidden secret is Ni -layer under Au coating |
| Ferrites | Coil cores, antennas, shields for HF applications | |
| | | |
| High coercitive material parts | Magnetic field shielding, example in speakers | MuMetal, Permalloy |
| | | |
| Current wire | Wires in PWB, DC/DC coils, actuators | |
| Coils or solenoids with current | DC/DC coils, actuators | |

Table 2: Magnetic field source types

## 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/