BNO055

Handling, soldering & mounting instructions

Bosch Sensortec

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BNO055: Handling, soldering & mounting instructions

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1. About this document

This document describes the recommended conditions and parameters to be applied when handling, soldering and mounting BNO055 sensor to the PCB.

1.1 Who should read this manual?

This document is intended as a practical guidance for
- Hardware designer in terms of device handling, mounting, placement and environmental influences in the target system.
- Application engineers to deal with the disturbances caused due to the external magnetic fields.
In addition, it will also explain which phenomena can and also cannot be compensated for by software.

2. PCB Design and Device Placing recommendations

MEMS sensors are high-precision measurement devices which consist of electronic as well as mechanical silicon structures, designed for precision, efficiency and mechanical robustness.

However, in order to achieve best possible results for your design, the following recommendations should be taken into consideration when mounting the sensor on a printed-circuit board (PCB).

It is generally recommended to keep a reasonable distance between the sensor mounting location on the PCB and the critical points described in the following examples. The exact value for a "reasonable distance" depends on many customer specific variables and must therefore be determined case by case on system level.

2.1 Push-button contacts

Keep a reasonable distance to push-button contacts, when placing the sensor device. Do not position the sensor directly beneath a push-button contact.

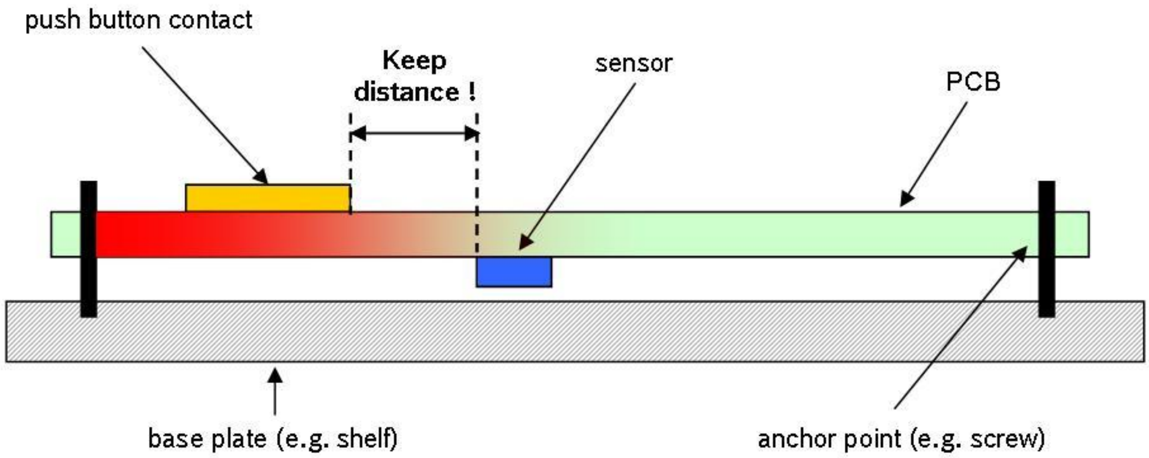

Figure 1: Push-button contacts

2.2 Thermal hot-spots on the PCB

Keep a reasonable distance from any thermal hot spots, when placing the sensor device. Hot spots can for example be other integrated circuits with high power consumption.

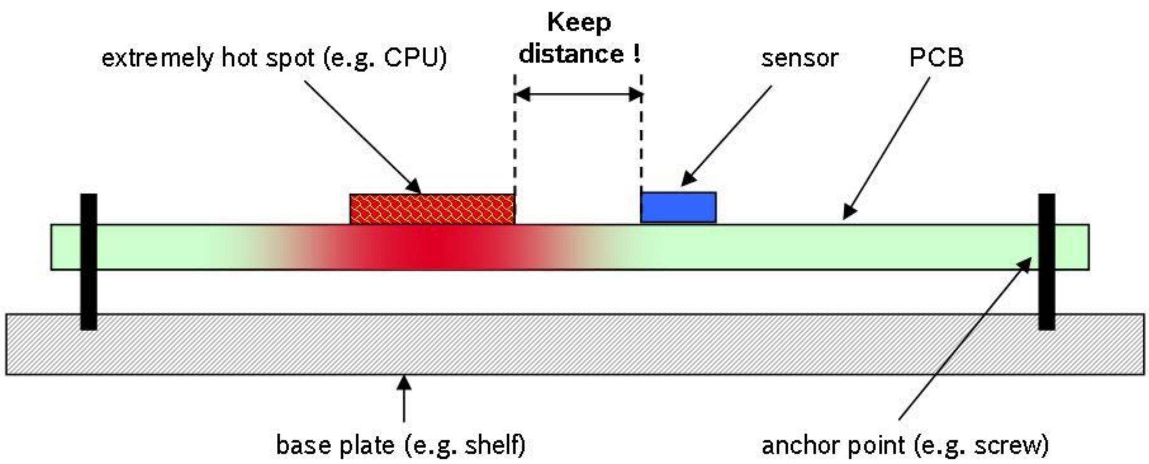

Figure 2: Thermal hot-spots on the PCB

2.3 Distance to PCB anchor points

Keep a reasonable distance from any anchor points, where the PCB is fixed at a base plate (e.g. like a shelf or similar), when placing the sensor device.

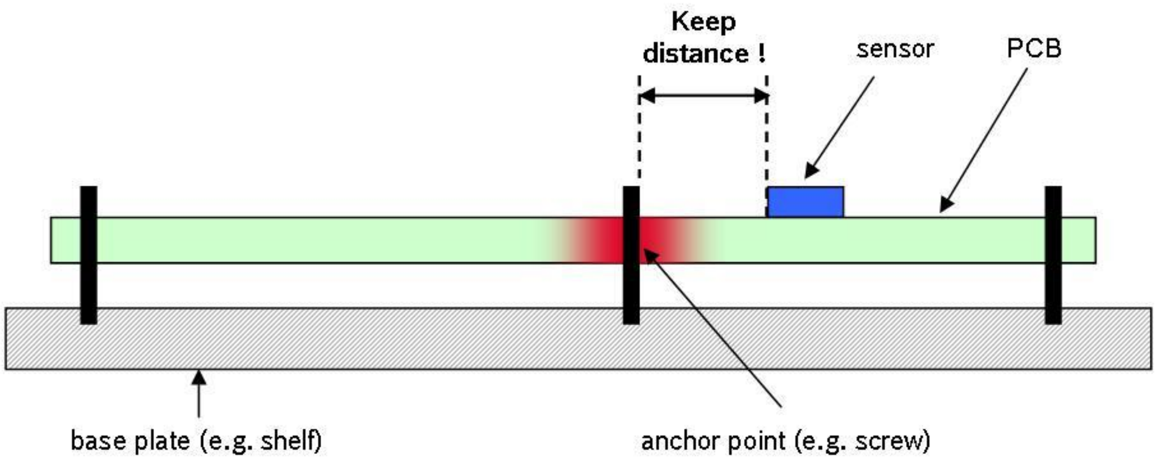

Figure 3: Distance to PCB anchor points

2.4 Vibrations on the PCB

Do not place the sensor in areas where resonant amplitudes (vibrations) of the PCB are likely to occur or to be expected.

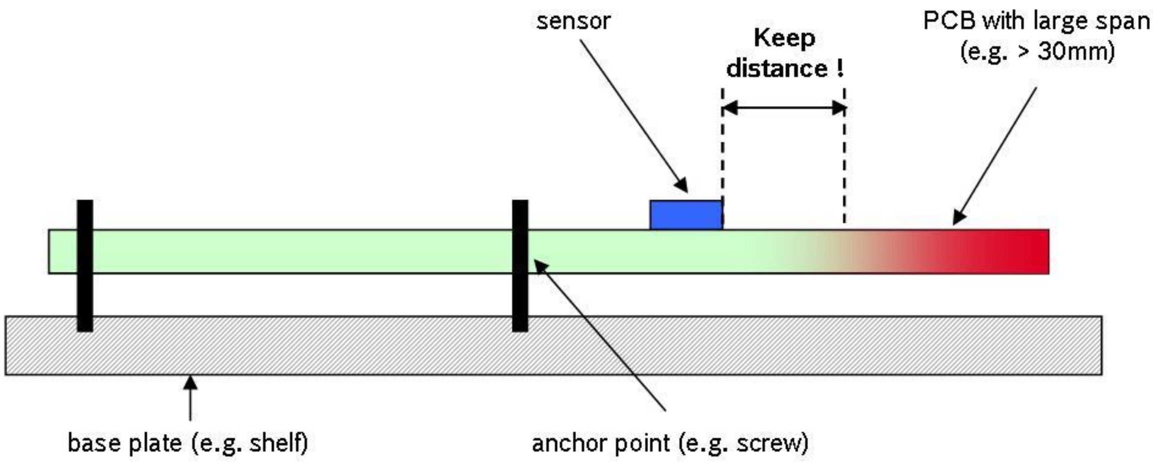

Figure 4: Vibrations on the PCB

2.5 Redundant PCB anchor points

It is recommended to unscrew or remove any redundant PCB anchor points. In theory, an ideal flat plane is determined exclusively by 3 anchor points. Any further anchor point will over-determine the ideal flat plane criteria. If these redundant anchor points are out of plane position (which means not 100% exact in plane position) the ideal flat criteria is infringed, resulting in mechanical stress.

The below given figure describes an expected stress maximum in the center of the diagonal crossover, assuming that the 4 anchor points are not 100% exact in plane (over-determined ideal flat plane criteria). Unscrewing or removing one of the redundant anchor points can significantly minimize mechanical stress.

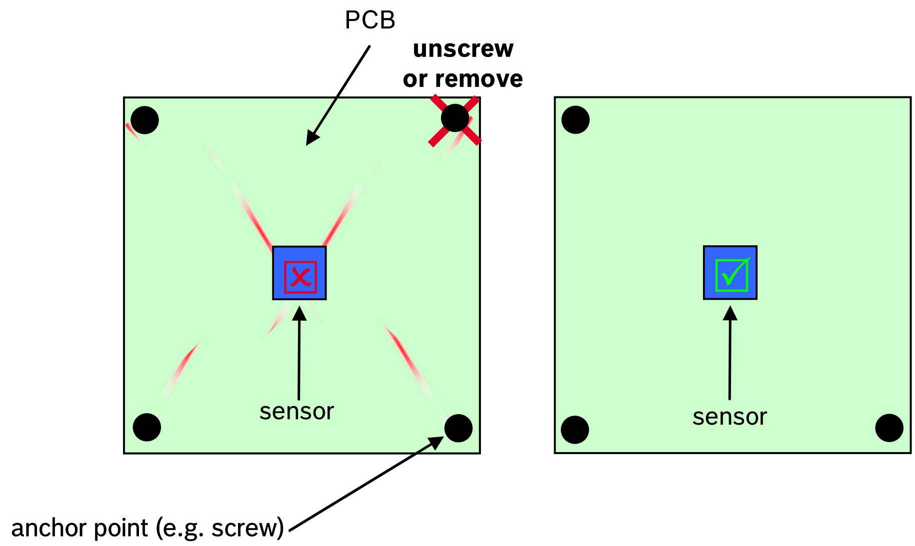

Figure 5: redundant PCB anchor points

2.6 Mechanical stress maximum on the PCB

It is recommended to keep a reasonable distance from any mechanical stress maximum, when placing the sensor device. Mechanical stress can be induced for example by redundant anchor points, as described in 5.2.3.

The below given example will show a stress maximum in the center of the diagonal crossover of the 4 anchor points. It is good manufacturing practice to always avoid or reduce the mechanical stress by optimizing the PCB design first, then to place the sensor in an appropriate low stress area.

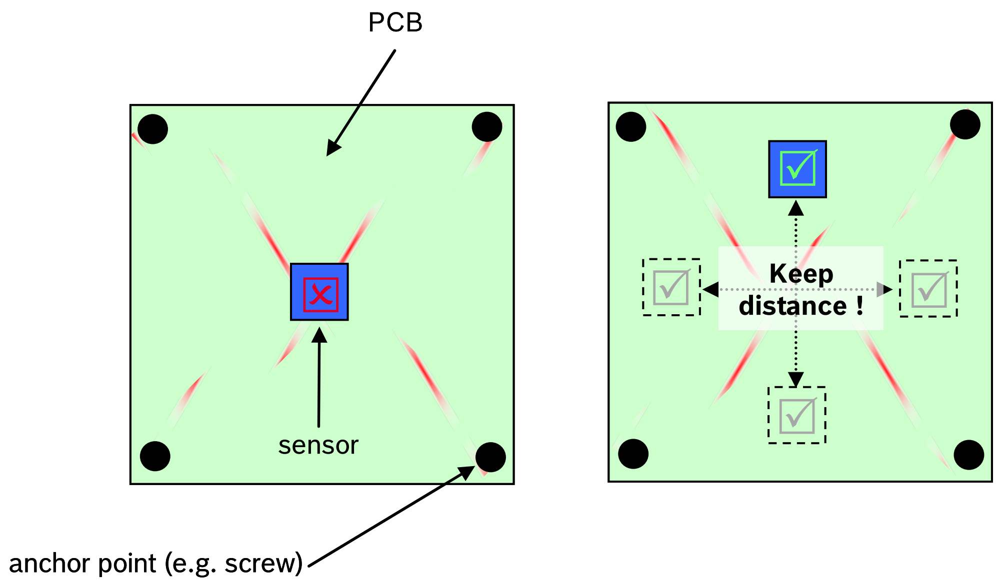

Figure 6: Mechanical stress maximum on the PCB

2.7 Resin coatings

As shown in the figure below, ensure that the sensor is neither partially covered nor in contact with any (epoxy) resign material leading to an un-symmetric stress distribution over the sensor package.

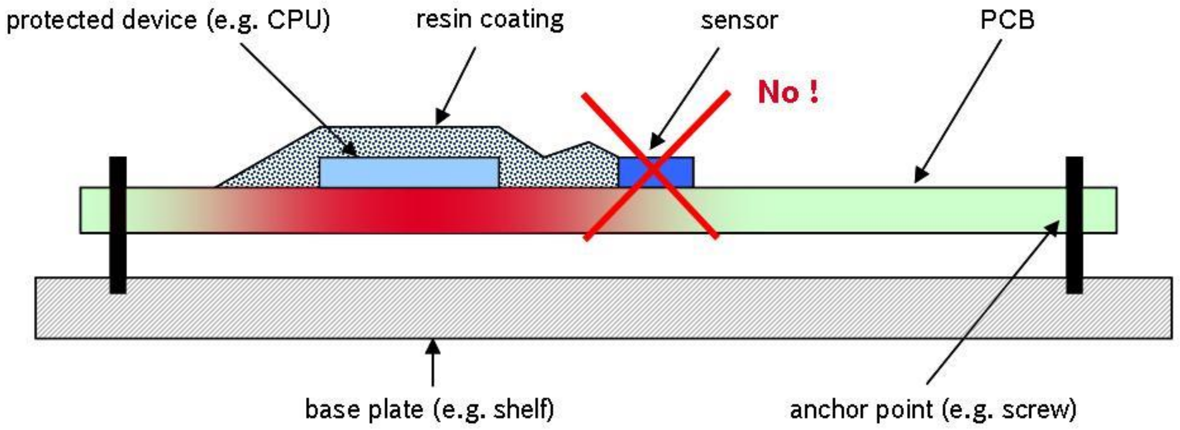

Figure 7: Resin coatings

3. PCB placement guideline based on magnetic influences

3.1 Non-geomagnetic field sources

The magnetic field measured by a geomagnetic sensor is a superposition of earth magnetic field and other environmental influences such as adjacent magnetic materials or fields induced by electric currents.
In this chapter, two other sources will be named, their strength will be compared to that of the geomagnetic field, and the implications for geomagnetic sensor applications will be explained.
The sources relevant for geomagnetic sensor applications are hard ferromagnetic materials and electric currents. Other sources do exist, but are not relevant for geomagnetic sensor applications. Please note that the majority of disturbances stemming from the device (adjacent magnetic materials) are effectively compensated by the Sensor fusion software.

3.1.1 **On-board: Hard ferromagnetic materials**

A hard magnetic material possesses a strong intrinsic magnetisation, which hardly reacts to external fields. These materials are typically used in speaker magnets and electrical motors (which are used for vibration alarm). Many different hard magnetic materials alloys exist. Some low-cost materials are: ferrites (BaFeO, SrFeO, ...) and AlNiCo; high-performance materials are for example SmCo and NdFeB.

The field strength of these fields is temperature-dependent. For the popular low-cost ferrite magnets, the field decreases on rising temperature at a rate of typically 0.2 %/K; most other materials have a lower temperature coefficient. When operating a geomagnetic sensor in a ferrite-caused offset field of 500 µT, the offset will shift by 10 µT on a change of 10° C (18° F). If not detected, this will cause a major miscalculation of heading.

3.1.2 **On-board: Current-induced fields**

Magnetic fields occur around electrical currents. The field direction follows the right-hand rule, which is depicted in Figure 8.

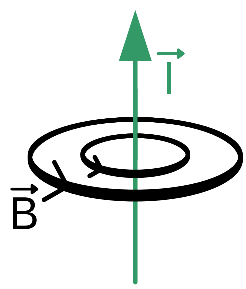

Figure 8: The right-hand rule for current-induced magnetic fields

The absolute magnetic field strength B at a given point outside of the wire depends on the current flowing through the wire and the distance to its centre according to the following formula:

$$B = \mu_0 \cdot \mu_r \cdot \frac{I}{2\pi r}, \text{ where}$$

$$\mu_r = \text{relative permeability} \approx 1 \text{ for air, and}$$

$$\mu_0 = \text{vacuum permeability} = 4\pi \cdot 10^{-7}\ H/m$$

Equation 1

As an example, a power line on a PCB could carry a current of 100 mA. At a distance of 5 mm from this line, the magnetic field strength equals:

$$B = \mu_0 \cdot \mu_r \cdot \frac{I}{2\pi r} = 4\pi \cdot 10^{-7} \frac{H}{m} \cdot 1 \cdot \frac{100\ mA}{2\pi \cdot 5\ mm} = 4\ \mu T$$

Equation 2

As a typical value for the horizontal geomagnetic field strength is 20 µT, a current-induced field can strongly influence heading calculation results, so that some distance must be kept. However, this is only the case for high-current lines, signals lines (e.g. an SPI bus) do not cause distortions.

3.1.3 **Comparison of geomagnetic field strength to other fields**

The geomagnetic field is very weak compared to other sources of magnetism. A typical speaker magnet can generate a field of 11,000 µT, which by far exceeds the strength of the earth magnetic field. The calculation above shows that, at least at close distances, current-induced fields can generate fields with strengths similar to the geomagnetic field.

3.2 Distortion and shielding by soft magnetic materials

The measurement of the earth magnetic field is not only affected by the existence of the other field sources named in chapter 5.1, but also the materials that can distort the surrounding fields. These materials are called soft magnetic materials. Unlike hard magnetic materials, these materials easily change their magnetisation based on the surrounding fields and attract the magnetic field lines. This leads to two phenomena: distortion and shielding.

3.2.1 **On-board: Distortion**

For a geomagnetic sensor, distortion is the effect that the field lines near soft magnetic materials are ‘bent’, so that their direction is changed from large-scale geomagnetic field direction. An example is given in Figure 9, where this field visible to the sensor is not pointing in the direction of magnetic north anymore. In addition, many soft magnetic materials are anisotropic, which means that the behaviour depends on the direction of the field applied.

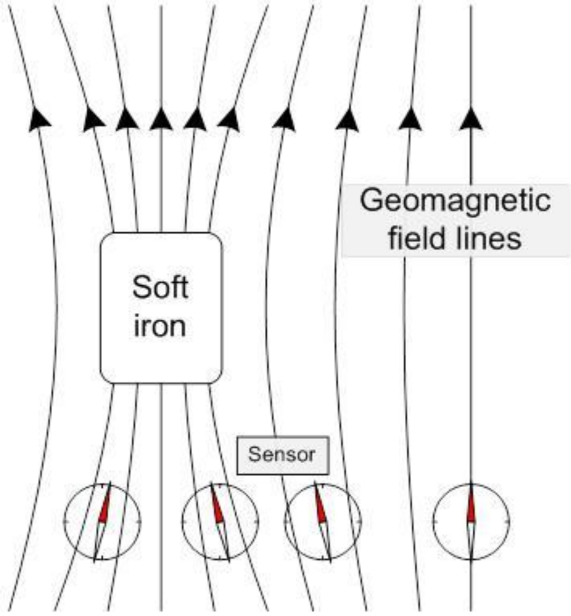

Figure 9: Magnetic field distortion due to soft iron effects

Software compensation of this effect is very difficult. For maritime applications, geomagnetic sensors are calibrated to correct the soft magnetic effects of the ship's iron. If no precise calibration is possible, such as in consumer applications, soft magnetic materials should be avoided in the vicinity of geomagnetic sensors.

3.2.2 **On-board and external: Shielding**

If a space is surrounded by soft magnetic material (solid or framework), this surrounding will absorb all of the magnetic field lines. This is depicted in Figure 10. As a result, there will be virtually no remaining field within the structure. If this effect is desired, the materials like the commercially available Mu-metal can be used as magnetic shielding.

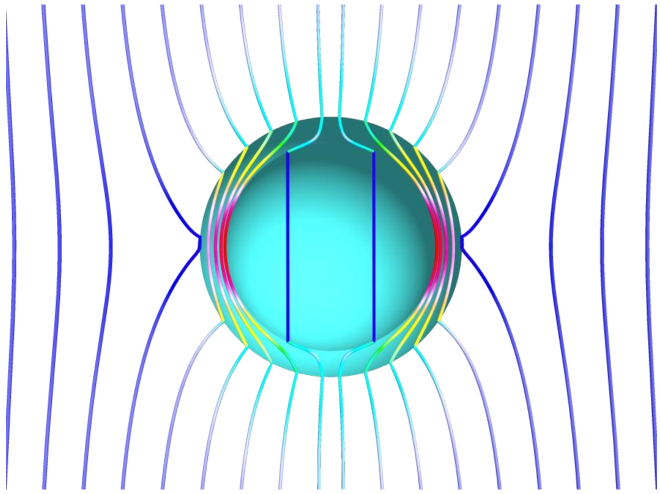

Figure 10: Magnetic shielding within a soft magnetic sphere (source: Institute for Theory of Electrical Engineering, Universität Stuttgart)

A geomagnetic sensor cannot work without the external magnetic field. Hence, the better the shielding is, the less signal is available for the geomagnetic sensor to work with. Especially the iron frame of buildings can be an unwanted cause of magnetic shielding. This explains why geomagnetic sensor performance can suffer within a building containing steel.

3.2.3 Overview of external influences

In this chapter, many possible external influences to geomagnetic sensor performance have been discussed. For a better overview, the impact on geomagnetic sensor input will now be given in Figure 11, in which the field in X and Y direction over a 360° geomagnetic sensor rotation is depicted. A centered circle depicts ideal geomagnetic sensor input; the distortions are clearly visible.

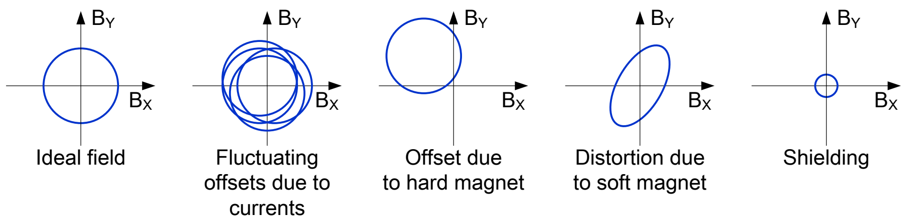

Figure 11: Overview of the effects of external influences on geomagnetic sensor input

3.3 Possibilities and limitations of software compensation

The effects mentioned in the previous chapter can partially be corrected by software.

On-board hard magnetic offsets are almost unavoidable in most of the environment and therefore it needs a calibration phase. In this calibration phase, the offset is estimated so that it can be subtracted from further measurements. This initial calibration is depicted in Figure 12.

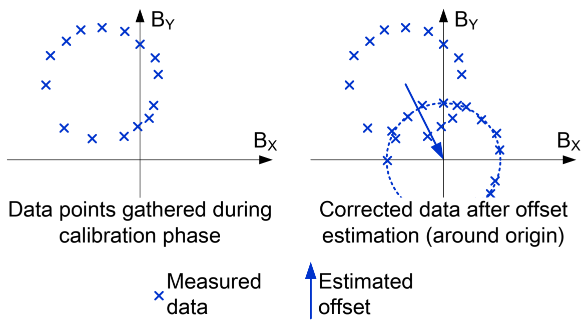

Figure 12: Offset estimation in calibration phase.

However, if the hard magnetic offsets exceed the sensor range, the sensor will become saturated and heading cannot be measured anymore.

The temperature dependence of the hard magnetic offsets will cause the originally estimated offset to change when temperature changes. If the sensor does not see many different orientations after the original calibration, this change may go unnoticed and result in a significant error (e.g. ~15° heading error on 5°C change of a 500 µT offset magnet).

Figure 13 illustrates this. The centre of the blue circle is the offset caused by permanent magnets. The radius of the blue circle equals the magnitude of the earth magnetic field.

The blue x marks the measured field strength. This is going directly in +y direction from the circle's centre. The correct heading can only be estimated after the circle's centre has been moved to the axes' origin (second image). When the offset changes (third image), while the offset compensation still subtracts the same value, the estimated heading is again wrong.

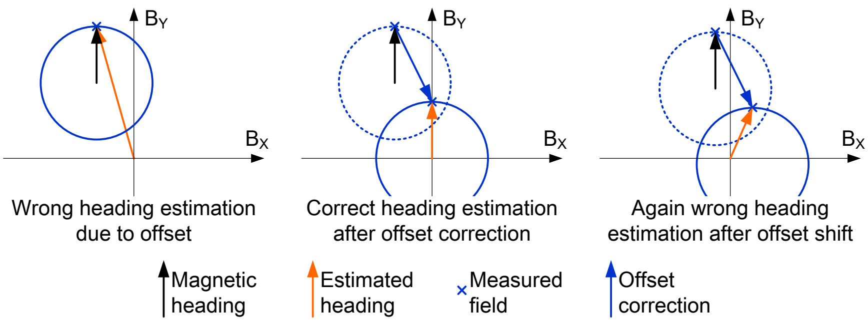

Figure 13: Errors caused by changing magnetic offsets

On-board current-induced fields change unpredictably (e.g. on display brightness change, during network activity ...). Because of this, their effects cannot be compensated and the fields will appear to add small varying offsets (appearing like noise) or large offsets to the sensor signal.

On-board soft magnetic effects are very difficult to compensate for. Since soft magnetic materials can distort or bend the geomagnetic field in different directions, depending on temperature, field strength and magnetic history of the material involved, a very large data set would be required to estimate all magnetic effects.
For these reasons, soft magnetic materials must (and can) be avoided in the vicinity of a geomagnetic sensor instead of being compensated in software.

On-board or external shielding due to on-board soft magnetic cover or external iron in buildings can attenuate the earth magnetic field so much that it becomes almost immeasurable. External effects cannot be estimated by the compass software and therefore cannot be compensated. On-board shielding will still dampen the signal so much that reliable heading estimation becomes impossible.

3.4 PCB placement advice

In order to achieve optimum geomagnetic sensor performance, several rules need to be kept in order to avoid the disturbances mentioned above.

3.4.1 **Position of the magnetic sensor element inside BNO055**

To ensure a maximum distance between the magnetometer inside the BNO055 and potentially disturbing ferro- and paramagnetic objects, the pcb designer may consider to orient the BNO055 in such a way, that the mentioned distance is maximized. The following figure shows the position of the magnetometer inside the package.

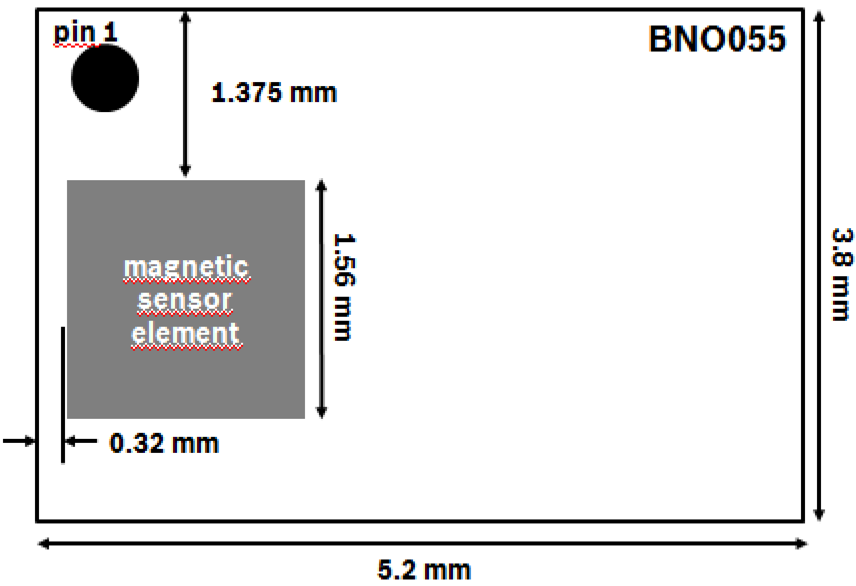

Figure 14: Position of magnetic sensor in BNO055

3.4.2 **Hard magnetic offsets**

Hard magnetic offsets must be as limited as much as possible. Ideally, the offset should be below 100 µT, maximum 200 µT. If this is not possible, please refer to the following two rules:
Sensor range may not be exceeded over entire temperature and magnet variation range. To keep to this rule, the offset at the proposed location should be measured. Then, using information about sample spread and temperature dependence of the magnet(s) that cause(s) this field, the effects over temperature can be estimated.
Example: A ferrite magnet has a temperature dependence of -0.2 %/K. A field of 600 µT measured at 20 °C will grow to (-0.002 x (-40 – 20) + 1) x 600 = 1.12 x 600 = 672 µT at a temperature of -40 °C. In order to accommodate for magnet variance as well, we recommend not using more than 75 % of the magnetic sensor range at room temperature. This results in the following rule:

$$B_x, B_y, B_z < 0.75 \cdot 1300\,\mu T$$

Equation 3

Not following this rule would result in certain conditions, wherein the sensor range will be exceeded and geomagnetic sensor functionality will be lost.

External field temperature effects must be minimized. Even if the range of the sensor is large enough to cope with the offset present, its temperature dependence will still impact geomagnetic sensor performance. Recommendation is to have no more than 200µT absolute field strength (i.e. $\sqrt{(X^2+Y^2+Z^2)}$) assuming a temperature coefficient of -0.2 %/K. if the temperature coefficient is lower, the value of 200 µT can be increased accordingly (e.g. 400 µT for a coefficient of 0.1%/K). This results in the following rule:

$$\sqrt{B_x^{\,2}+B_y^{\,2}+B_z^{\,2}} \cdot TC_{magnet} < 200\mu T \cdot 0.2 \,\%\!/\!K$$

Equation 4

Not following this rule can result in noticeable temperature dependence of the geomagnetic sensor.

3.4.3 **PCB Currents**

Constant currents on the PCB cause a constant offset on the sensor signal and are compensated by software. However, if fluctuating currents are routed closely to the magnetic sensor, then the changing field strength caused by such a current should not exceed 0.5 µT, while lower numbers are better. Following equation 5, for a given current I_{fluc}, the required distance equals:

$$r = \frac{\mu_0 \cdot \mu_r}{2\pi \cdot B} \cdot I_{fluc} = 0.4 \cdot I_{fluc}, \text{ using}$$
$$\mu_r = \text{relative permeability} \approx 1 \text{ for air,}$$
$$\mu_0 = \text{vacuum permeability} = 4\pi \cdot 10^{-7}\ H/m,$$
$$I_{fluc} = \text{fluctuating current, and}$$
$$B = \text{allowed fluctuating field strength } (0.5\,\mu T)$$

Equation 5

Please use the following table to estimate the required distance between the current line and the geomagnetic sensor:

Table 1: Required distance between magnetic sensor and current lines

Current change (max-min) [mA]	Required distance [mm]
1	0.4
2	0.8
5	2.0
10	4.0
20	8.0
50	20.0

3.4.4 **Soft magnetic effects**

The usage of soft magnetic materials close to the geomagnetic sensor must be avoided. The presence of soft magnetic materials at the sensor can be estimated by rotating the PCB on a nonmagnetic table (free of iron). Ideally, the measured data points will all be in a circle. In usual cases, soft magnetic effects are visible as distortion of this circle into an ellipse as visible in Figure 15.

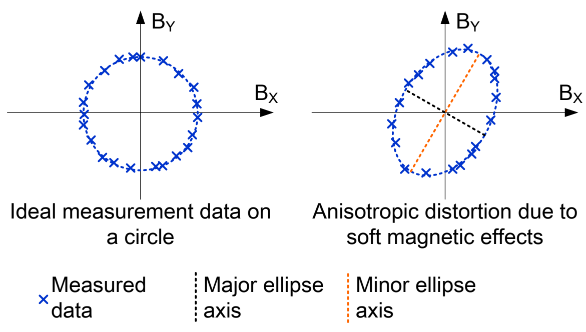

Figure 15: Quantifying soft magnetic distortion

If the distortion can be approximated by an ellipse, the ratio between major and minor ellipse axis defines the soft magnetic effect. The mismatch should be below 3 %, resulting in the last rule:

$$\frac{L_{major\_axis}}{L_{minor\_axis}} < 1.03 \qquad \text{Equation 6}$$

3.4.5 **Overview**

An overview of the previously presented rules are shown in the table below

Table 2: Overview of placement guidelines

Hard magnetism	
Ideal:	External field < 100 µT
Second best:	External field < 200 µT
Otherwise:	External field < 0.75 x sensor range (room temperature), and sqrt(BX²+ BY²+ BZ²) x TCext. field < 0.40 µT x %/K
Fluctuating PCB currents	
Distance r [mm] > 0.4 x Ifluc [mA]	
Soft magnetism	
Ratio major axis / minor axis < 1.03	

4. PCB layout recommendation

The following general rules are recommended

- PCB land width = LGA solder pin width
- PCB land length = LGA solder pin length + 0.1 mm on each side
- Solder mask opening width = PCB land width + 0.05 mm on each side
- Solder mask opening length = PCB land length + 0.05 mm on each side

5. Reflow soldering

To ensure that sensors are properly mounted it is important to avoid mechanical stress by ensuring a proper solder thickness after soldering. Furthermore solder paste thickness after soldering should be as uniform as possible to reduce uneven stress

5.1 Recommendation about stencil design and solder paste application

- It is recommended to keep the openings of the stencil mask for the signal pads between 70% and 90% of the PCB pad area.
- An accurate alignment of the stencil and the printed circuit board (within 0.025mm) is recommended.
- A stencil thickness of 80 – 150 µm is recommended for screen printing

5.2 Recommendation for soldering of sensors in LGA package

Please ensure that the edges of the LGA substrate of the sensor are free of solder material. It is not recommended to allow solder material forming a high meniscus covering the edge of the LGA substrate (compare figure below).

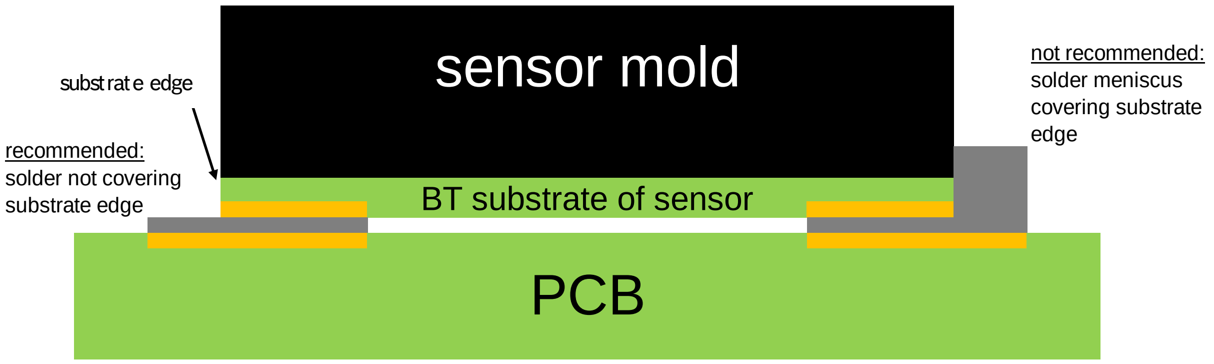

Figure 16: Recommendation to keep the side of LGA free from solder material

Using copper under fill (peel cut) for the LGA package is forbidden, compare figure below.

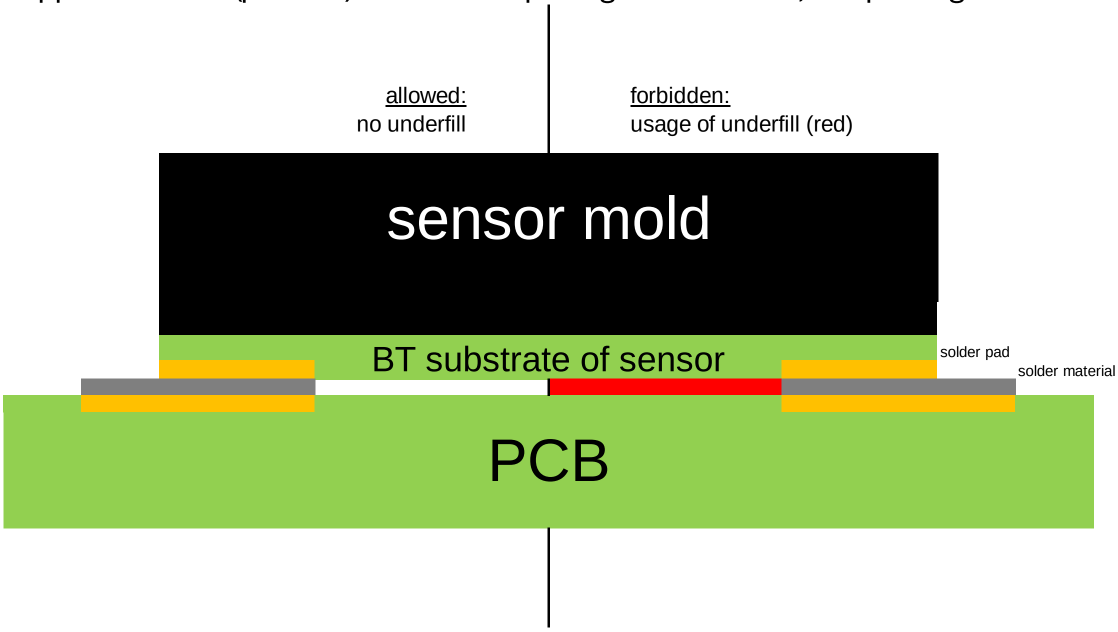

Figure 17: Recommendation not to use under fill for LGA packages

5.3 Classification reflow profiles

Profile Feature		Pb-Free Assembly
Average Ramp-Up Rate (Ts_{max} to Tp)		3° C/second max.
Preheat – Temperature Min (Ts_{min}) – Temperature Max (Ts_{max}) – Time (ts_{min} to ts_{max})		150 °C 200 °C 60-180 seconds
Time maintained above: – Temperature (T_L) – Time (t_L)		217 °C 60-150 seconds
Peak/Classification Temperature (Tp)		**260 °C**
Time within 5 °C of actual Peak Temperature (tp)		20-40 seconds
Ramp-Down Rate		6 °C/second max.
Time 25 °C to Peak Temperature		8 minutes max.

Note 1: All temperatures refer to topside of the package, measured on the package body surface.

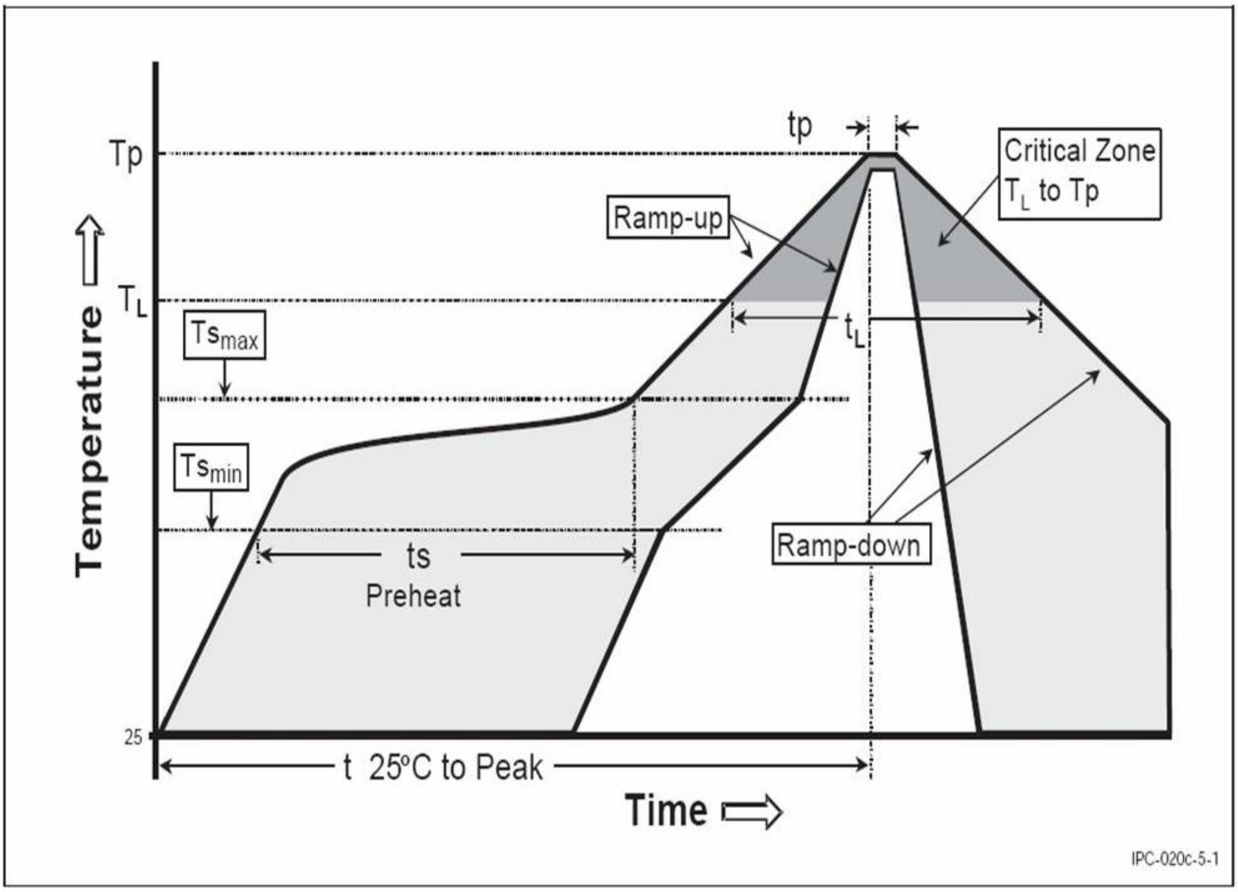

Figure 18:Recommended solder profile

5.4 Multiple reflow soldering cycles

The product can withstand in total up to 3 reflow soldering cycles.

This could be a situation where a PCB is mounted with devices from both sides (i.e. 2 reflow cycles necessary) and in the next step an additional re-work cycle could be required (1 reflow).

6. Legal disclaimer

6.1 Engineering samples

Engineering Samples are marked with an asterisk (*) or (e) or (E). Samples may vary from the valid technical specifications of the product series contained in this data sheet. They are therefore not intended or fit for resale to third parties or for use in end products. Their sole purpose is internal client testing. The testing of an engineering sample may in no way replace the testing of a product series. Bosch Sensortec assumes no liability for the use of engineering samples. The Purchaser shall indemnify Bosch Sensortec from all claims arising from the use of engineering samples.

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The purchaser must monitor the market for the purchased products, particularly with regard to product safety, and inform Bosch Sensortec without delay of all security relevant incidents.

6.3 Application examples and hints

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7. Document history and modification

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