# TN1383

Technical note

# PCB design guidelines for MEMS sensors

## Introduction

This technical note provides PCB design guidelines for obtaining optimal performance from MEMS sensors, including solutions for thermomechanical stress, rules for PCB layout, as well as placement recommendations.

# 1 Getting the best performance from MEMS devices

The basic rules to be followed in order to guarantee a good PCB design based on ST's MEMS technology are introduced in the following sections.

The reference for the layout guidelines is technical note TN0018 available from www.st.com.

“Do” and “don’t” recommendations that designers have to take into account during the PCB design are also described.

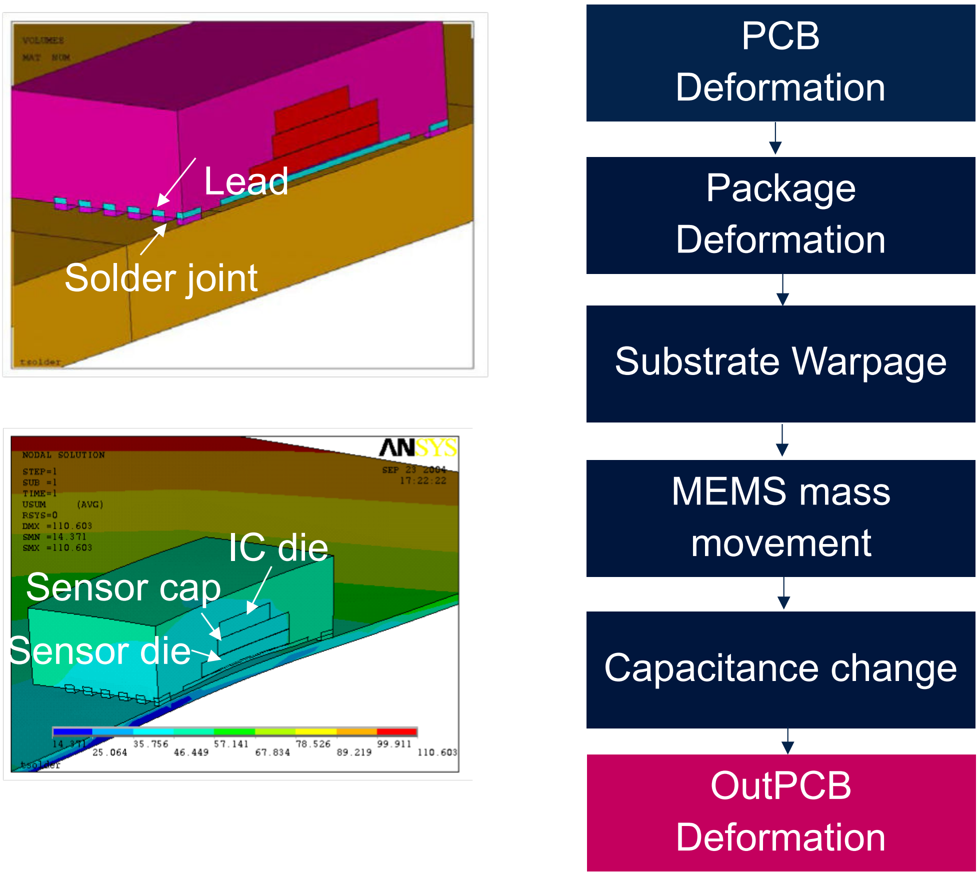
# 2 Effects of thermomechanical stress

## 2.1 Soldering effect on the MEMS

Assembly processes can induce thermomechanical stress to the sensor due to the interaction between the sensor die, package, and PCB.

Basically, the deformation of the PCB is transferred to the substrate and to the package of the sensor. Then the mechanical stress is transferred to the mechanical structure of the sensor through its anchors. This causes a deviation/drift of sensor parameters, such as offset, sensitivity, and self-test response. In the worst case, aggressive handling may lead to breakage of the structures of the sensor.

Figure 1. Consequences of thermomechanical stress

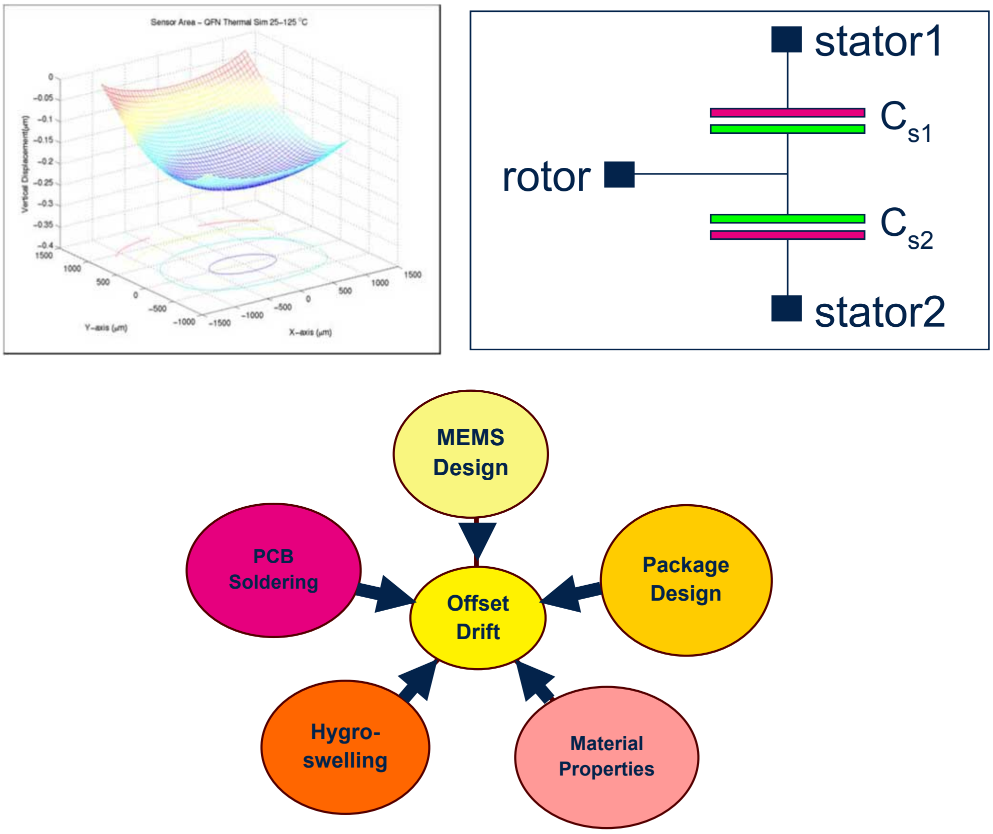


## 2.2 Effect of thermomechanical offset drift on the sensor

Thermomechanical stress causes a deformation of the silicon die of the sensor, which is converted into a relative displacement between the fixed and movable electrodes. For the sensors, this displacement produces a signal comparable to a real physical one. This produces, for example, a variation of the offset of the device.

The actual variation of the sensor parameters related to thermomechanical offset drift depends on several variables (package, materials, MEMS design, soldering process, and so forth).

Figure 2. **Offset drift resulting from thermomechanical stress**



## 2.3 Effect of thermomechanical stress: elastic vs. plastic

Thermomechanical stress, and related warpage, always happen when there are changes in temperature:

- It is usually an **elastic** effect.
- When the external force is removed, **warpage is relaxed**.
- Package materials have been selected and the sensor has been designed to **minimize this effect**.

During **soldering**, **plastic deformation** can happen in the package due to:

- Interaction with the **PCB**, **uneven force field**
- **Process not optimized**, for example, temperature ramp down in reflow oven

Plastic deformation does not relax back when the temperature stress is removed.

## 2.4 Mechanical stress factors

Uneven force field distribution is created by:

- Asymmetrical PCB layout, surrounding components, position of the vias (see Section 3 Importance of a good layout)
- Placement of MEMS component (see Section 4 Placement considerations for inertial MEMS sensors on the PCB)
- Usage and dispensing of filler
- Nonuniformity of solder paste thickness

Other factors to be considered for optimized performance are:

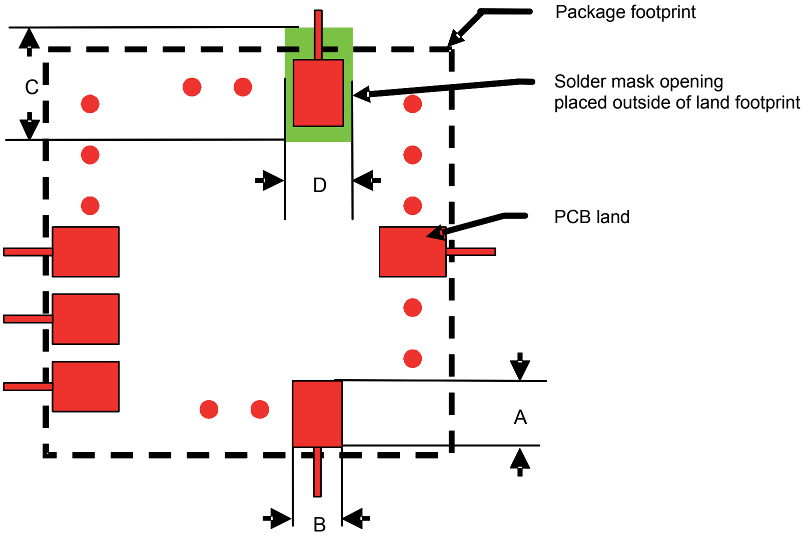
- Very thick solder paste reduces the level of warpage of the sensor.
- Slow cooling of the board after assembly (JEDEC specs) is recommended to avoid stress on the sensor.
- It is recommended to avoid *g*-forces exceeding the specified sensor limits during all handling operations, including transportation and assembly.

# 3 Importance of a good layout

## 3.1 PCB design rules for the footprint

Footprint design rules are taken from technical note TN0018. Note that all lands have to be the same size, no need for large lands.

Figure 3. Footprint design rules



PCB land design and connecting traces should be designed symmetrically.

**For LGA pad spacing greater than 200 µm:**

A = PCB land length = LGA solder pad length + 0.1 mm

B = PCB land width = LGA solder pad width + 0.1 mm

**For LGA pad spacing equal to or less than 200 µm:**

A = PCB land length = LGA solder pad length

B = PCB land width = LGA solder pad width

C = Solder mask opening length (where applicable) = PCB land length + 0.1 mm

D = Solder mask opening width = PCB land width + 0.1 mm

### Stencil design and solder paste application

The thickness and the pattern of the soldering paste are important for the proper MEMS sensor mounting process.

- Stainless steel stencils are recommended for solder paste application.
- A stencil thickness of 90 - 150 µm (3.5 - 6 mils) is recommended for screen printing.
- The openings of the stencil for the signal pads should be between 70% and 90% of the PCB pad area.
- Optionally, for better solder paste release, the aperture walls should be trapezoidal and the corners rounded.
- The fine pitch of the IC leads requires accurate alignment of the stencil to the printed circuit board. The stencil and printed circuit assembly should be aligned to within 25 µm (1 mil) prior to application of the solder paste.

## 3.2 PCB design rules for the traces

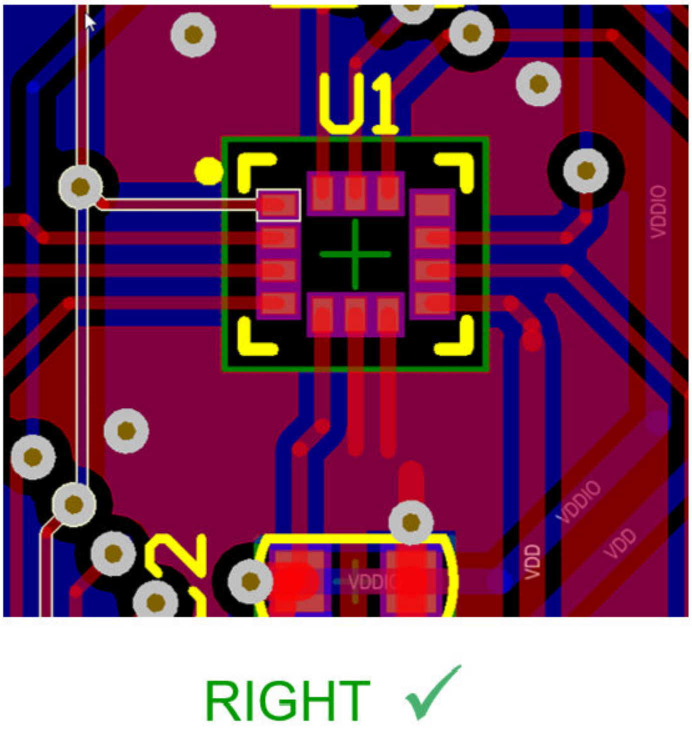
Connecting traces should be designed symmetrically.

All traces should flow outside the component, parallel to the long edge of the pad.

The traces must have the same thickness. There is no need to have thicker traces for power signals since very low current can flow into them. This is to avoid potential mechanical stress.

The ground plane should not be connected directly to the footprint pads. It is better to connect it through a standard trace.

**Figure 4. Correct traces**

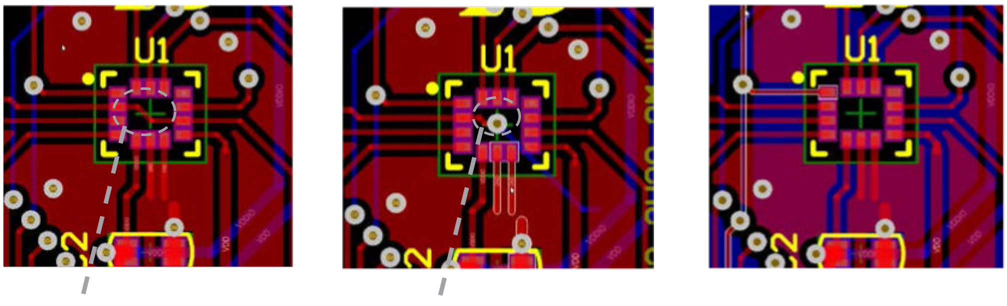


## 3.3 Placement rules for the top side

For all MEMS devices, the device is soldered on the top side.

Never place any routing or via on the top side under the device, refer to the following figure.

Figure 5. **Examples of top side placement**



**WRONG**: routing under the device on TOP side

**WRONG**: VIA under the device

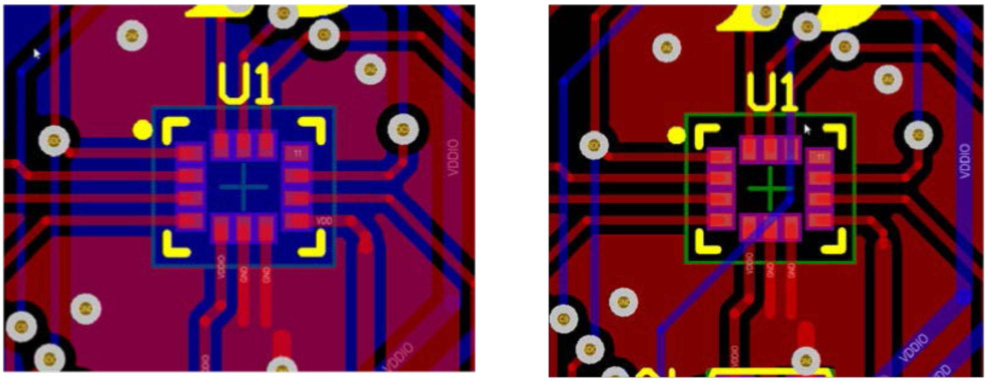
**RIGHT**: leave free space under the device on TOP side

## 3.4 Placement rules for the bottom side

Placement rules for the bottom side apply only to MEMS accelerometer, gyroscope, and pressure sensors.

It is possible to use the bottom side under the device for power plane or signal routing.

Figure 6. **Examples of bottom side placement**



**RIGHT**: power plane on BOTTOM side under the device

**RIGHT**: signal routing on BOTTOM side under the device

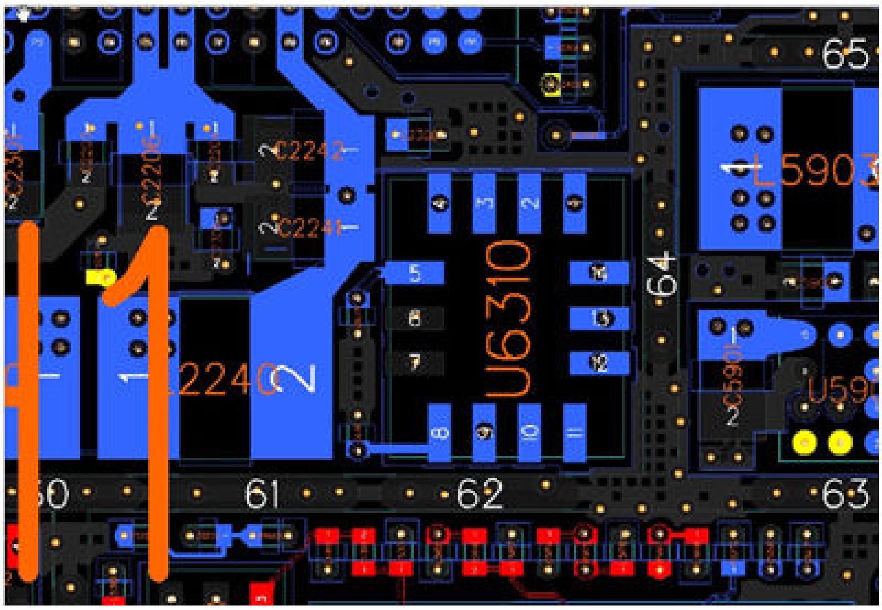
## 3.5 LGA package layout hints - extra tips

The following figure shows an actual case from the field.

The customer was facing a little offset shift on the zero-*g* and zero-rate level. The following points were identified as incorrect practices:

- Pin 6 and 7 are not soldered: this can cause mechanical stress on the inner sensors.
- Vias below pads: it is better to move these outside the component.
- Copper traces below the component have to be avoided (trace of pin 8 should flow directly outside the component).

**Figure 7. Example of incorrect layout from real case**



# 4 Placement considerations for inertial MEMS sensors on the PCB

## 4.1 Mechanical stress and layout tips

Thermomechanical stress is a normal process during component assembly and the effect is fully recovered once the stress conditions return to normal. In fact, even if the layout is symmetrical, the PCB and solder joints need time to relax the induced stress.

On the other hand, permanent unexpected levels of sensor output can be caused by anisotropic mechanical stress distribution on the PCB. This is typically generated by:

- Screw, holes, pillars
- Shields placed in close proximity to the device
- Underfill (when placed close or on the opposite side of the MEMS)

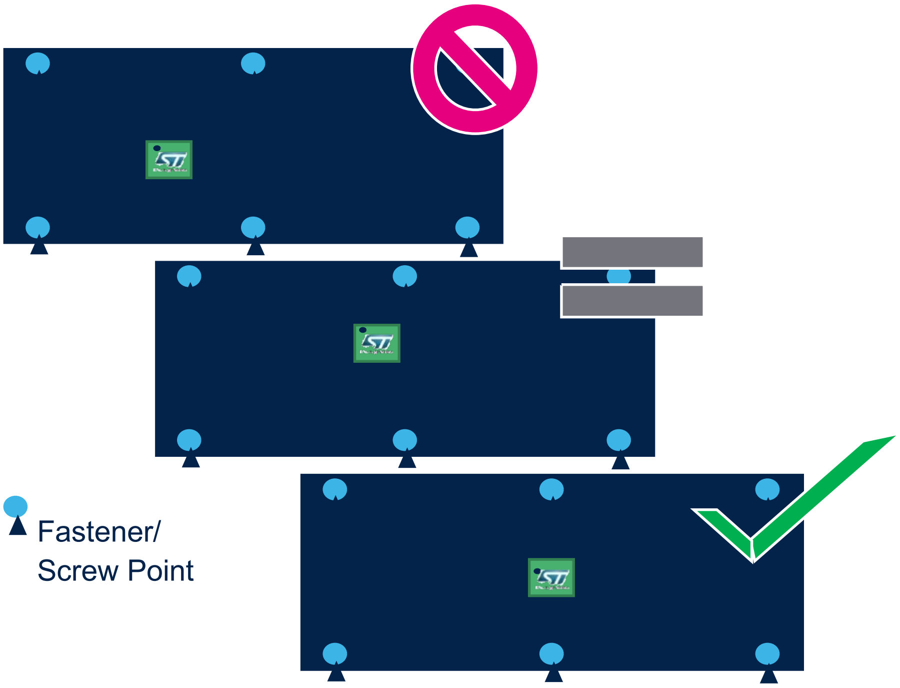
Moreover, in order to prevent high temperature gradients that could cause mechanical stress, ST recommends placing the sensor away from heat sources (such as batteries and power management integrated circuits).

All these elements should be carefully evaluated during the design of the PCB.

## 4.2 Fasteners on the PCB

PCB boards are generally housed and fixed in an enclosure. Inertial MEMS sensors should be located between fasteners so as to minimize and distribute homogenously the stress on the MEMS sensor as illustrated in the following figure. When this is not possible, the location that best meets this criteria is to be selected.

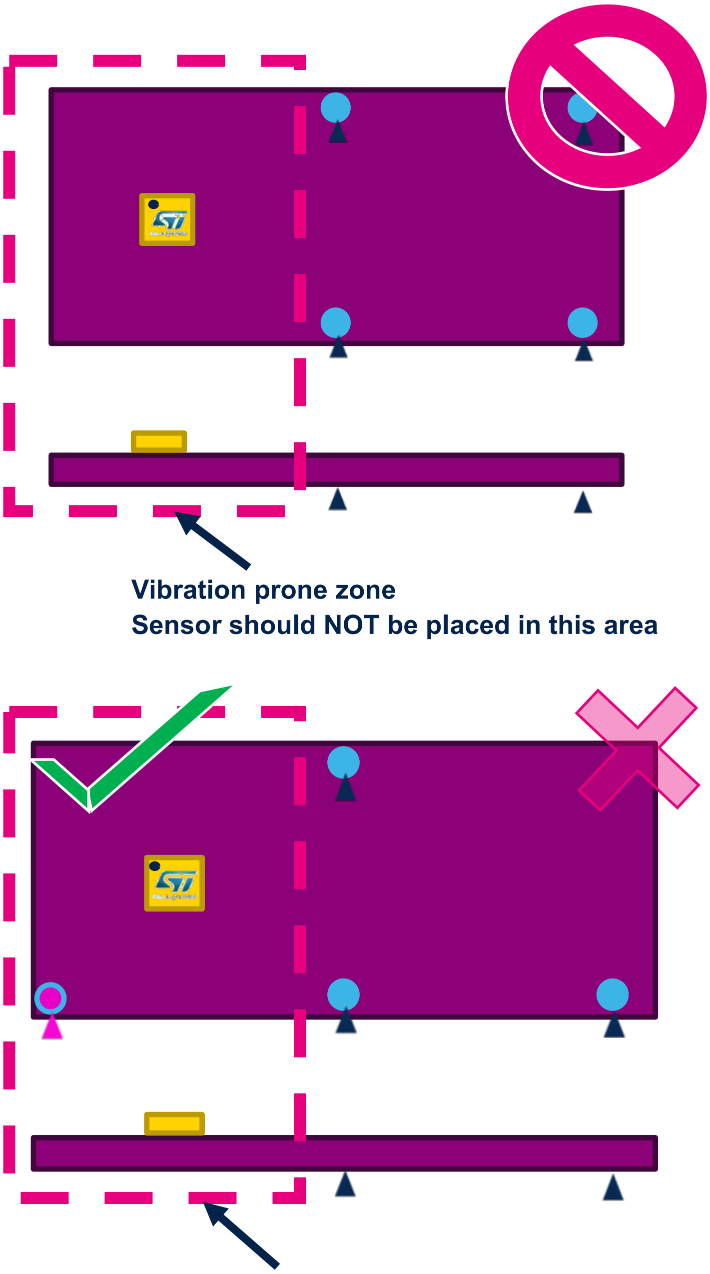
Figure 8. **Placement of sensor between fasteners**



## 4.3 Areas of stress on the PCB

The PCB board illustrated in the previous Figure 8 is a symmetric rectangular board. In actual applications, the probability of having a symmetric board is unlikely. In most cases, PCBs have protruding sections and without fasteners. These locations are prone to vibrations that can provide false readouts and thus it is highly advisable that the MEMS sensor be located away from such areas.

Figure 9. **Placement of sensor in area without vibrations**

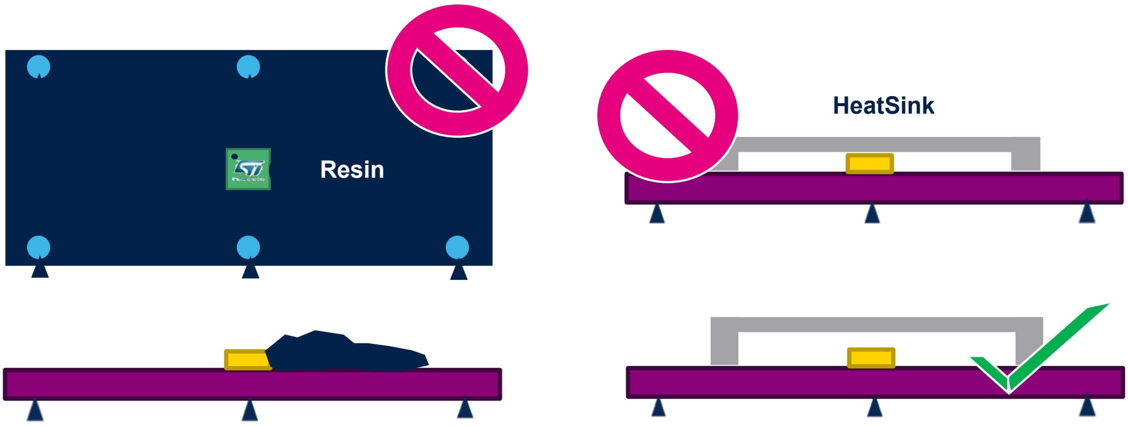


**Vibration prone zone**
**Sensor should NOT be placed in this area**

**Fastener relocated to vibration prone zone**
**(Relocation for same BOM purpose)**
**MEMS device is located equidistant from fasteners**

Sources of stress can be the use of epoxy resin materials to cover the CPU and the use of heat sinks or other foreign structures that are in contact with the MEMS sensors. These conditions are sources of high stress and need to be removed from the design.

Figure 10. **Examples of sources of stress to the sensor**

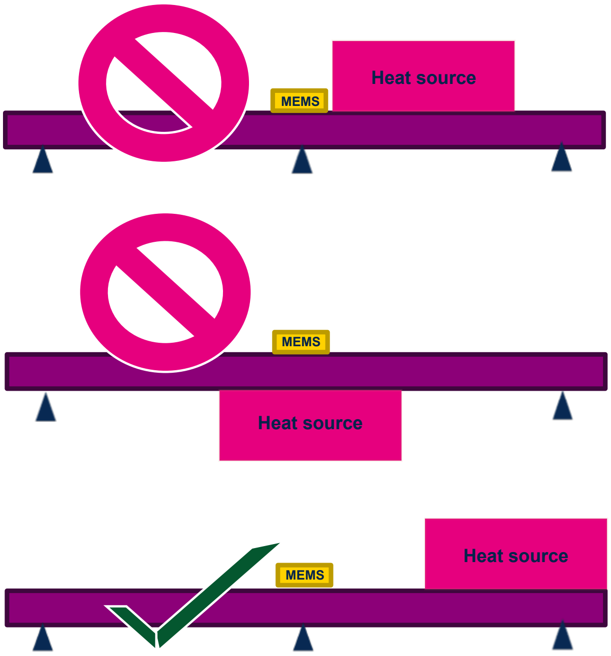


## 4.4 Recommended placement of a heat source with respect to the MEMS sensor

The presence of a heat source in the surrounding area of the MEMS sensor causes undesired internal movement.

In order to reduce the probability of mechanical stress, locating the heat source away from the MEMS sensor is recommended.

Figure 11. **Placement of the heat source far from the MEMS sensor**

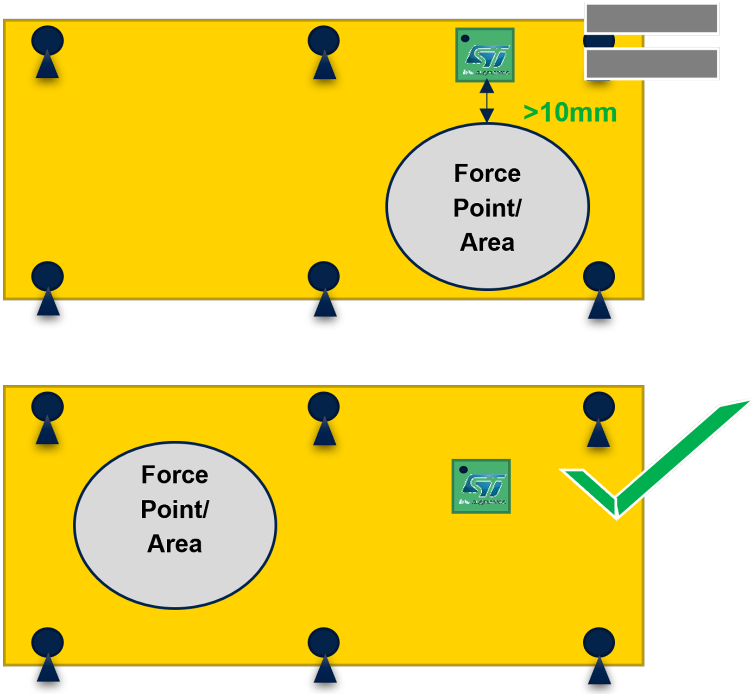


## 4.5 External loads/forces

Certain applications allow the possibility for external loads/forces to be exerted on the board. One example might be a series of pushbuttons or connection points that are used during normal operation.

These forces are transferred to the board and hence to the MEMS sensor. Placing the MEMS sensor away from these sources and keeping it at least 10 mm away from the source of the external force reduces the effect on the MEMS sensor.

**Figure 12. Placement of sensor far from external point of force**



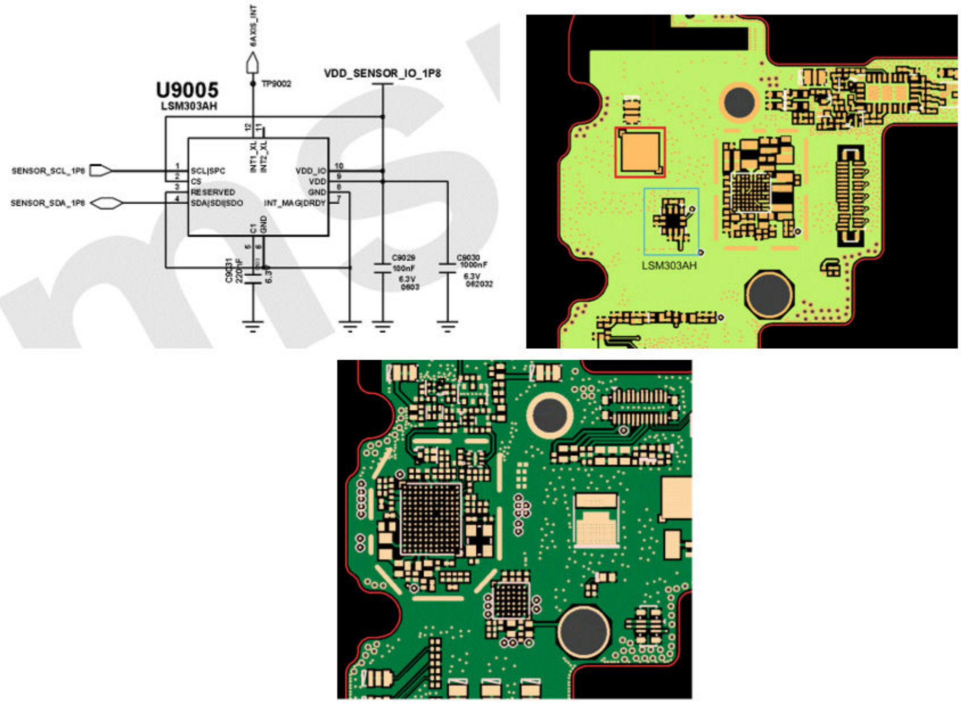
## 4.6 Example of shield placement

The schematic analysis of the PCB shows that it is properly designed according to ST guidelines.

On the other hand, the layout shows a metallic shield placed on the bottom side close to the MEMS component.

Based on ST's experience, this metallic shield can cause a small additional offset contribution on the device because it can cause mechanical stress.

Figure 13. **Example of shield placement**



## 4.7 Findings of shield mounting

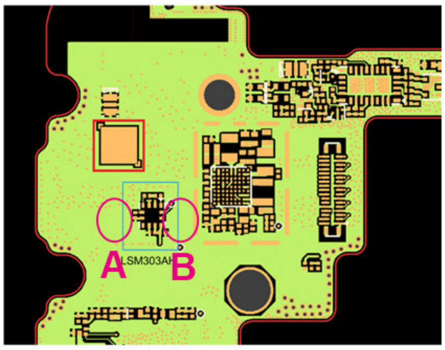
In order to estimate the effect of shield mounting, board bending has been evaluated using a profilometry analysis.

The profilometer allows measuring the radius of curvature $R_C$ of a given surface.

If the surface is flat, $R_C \rightarrow \infty$. This means that the lower the $R_C$, the higher the stress applied to the PCB.

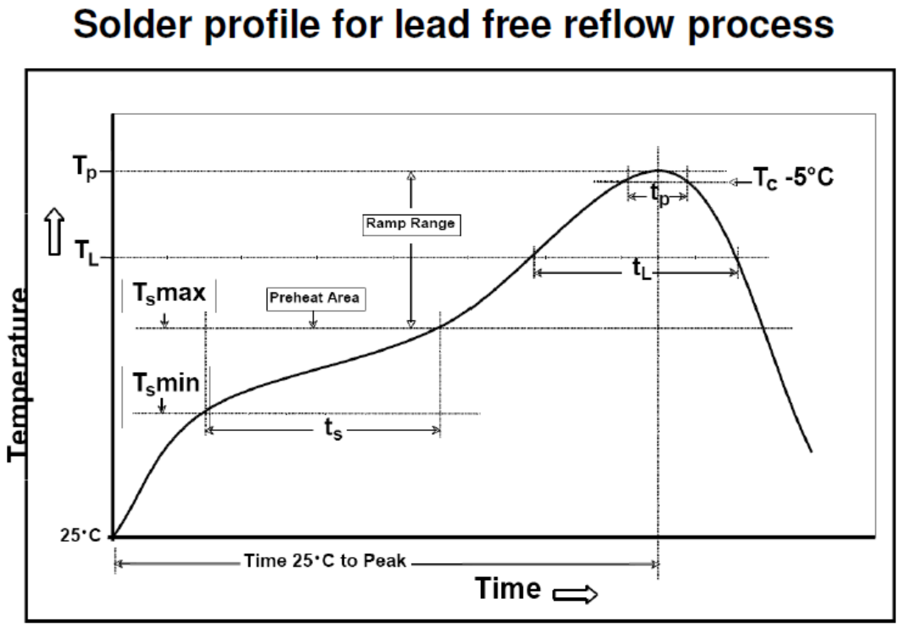
In the PCBs under test, $R_C$ has been measured in the A and B areas (refer to the figure below) and have been found to be much smaller than that of flat PCBs.

Figure 14. **Areas of measurement of radius of curvature**



## 4.8 Solder profile according to IPC/JEDEC J-STD-020D

Figure 15. Classification reflow profile for SMT components



refer to IPC/JEDEC J-STD-020D

Figure 16. Classification reflow profiles and temperature

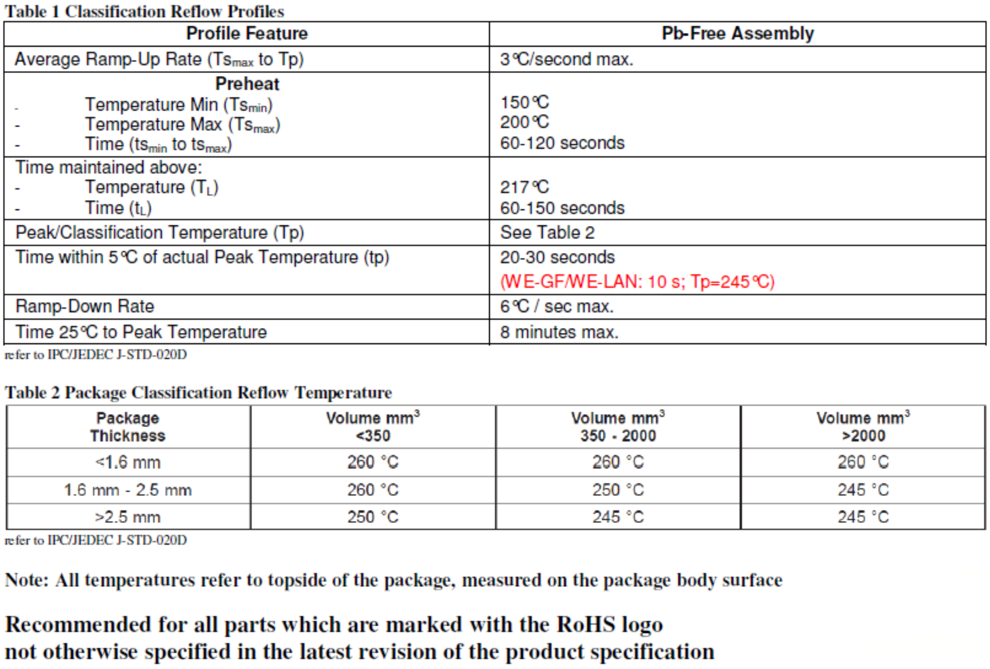


Table 1 Classification Reflow Profiles

| Profile Feature | Pb-Free Assembly |
|---|---|
| Average Ramp-Up Rate ($Ts_{max}$ to Tp) | 3°C/second max. |
| **Preheat**<br>- Temperature Min ($Ts_{min}$)<br>- Temperature Max ($Ts_{max}$)<br>- Time ($ts_{min}$ to $ts_{max}$) | 150°C<br>200°C<br>60-120 seconds |
| Time maintained above:<br>- Temperature ($T_L$)<br>- Time ($t_L$) | 217°C<br>60-150 seconds |
| Peak/Classification Temperature (Tp) | See Table 2 |
| Time within 5°C of actual Peak Temperature (tp) | 20-30 seconds<br>(WE-GF/WE-LAN: 10 s; Tp=245°C) |
| Ramp-Down Rate | 6°C / sec max. |
| Time 25°C to Peak Temperature | 8 minutes max. |

refer to IPC/JEDEC J-STD-020D

Table 2 Package Classification Reflow Temperature

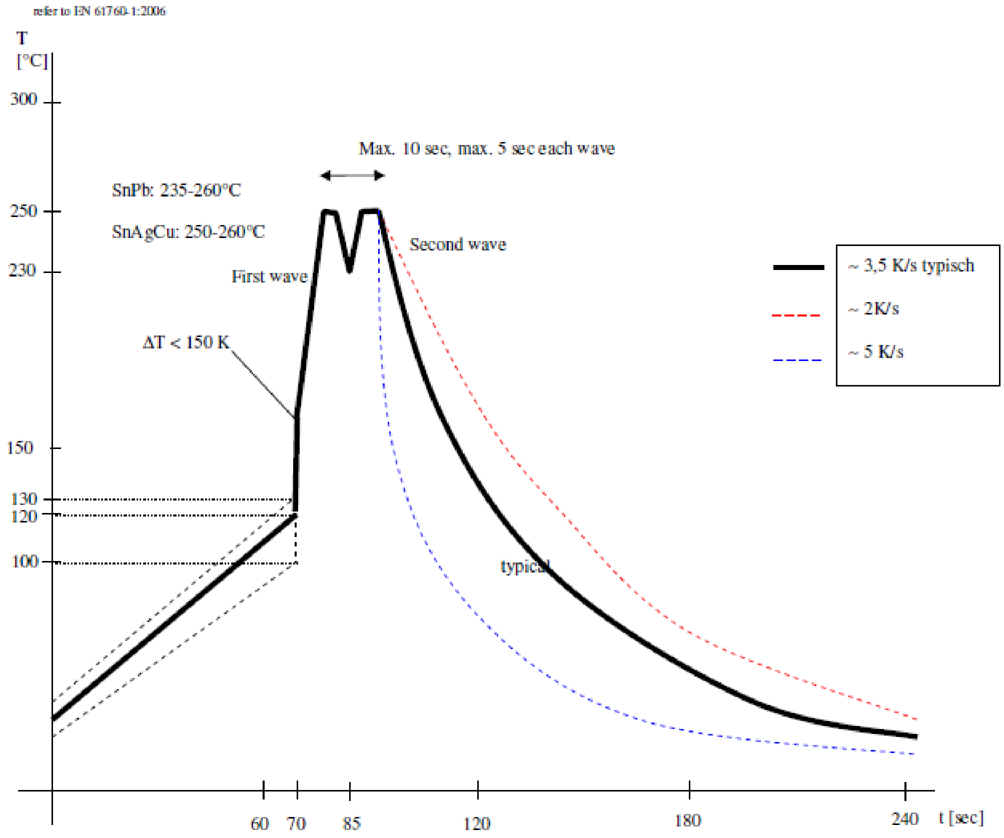
| Package Thickness | Volume mm$^3$ <350 | Volume mm$^3$ 350 - 2000 | Volume mm$^3$ >2000 |
|---|---|---|---|
| <1.6 mm | 260 °C | 260 °C | 260 °C |
| 1.6 mm - 2.5 mm | 260 °C | 250 °C | 245 °C |
| >2.5 mm | 250 °C | 245 °C | 245 °C |

refer to IPC/JEDEC J-STD-020D

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

**Recommended for all parts which are marked with the RoHS logo
not otherwise specified in the latest revision of the product specification**

Figure 17. **Classification wave soldering profile for THT components**

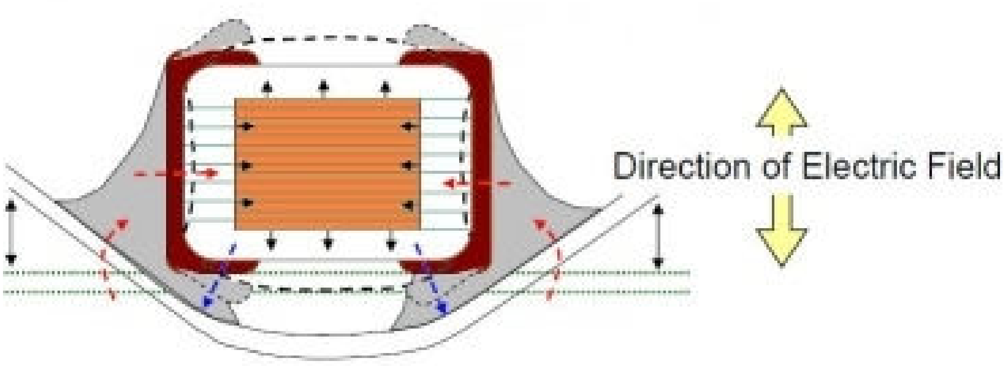


## 4.9 Avoiding the effect of singing capacitors on the performance of the MEMS sensor

In some applications, a vibration or low audible hum coming from certain ceramic capacitors can arise. This is sometimes described as a singing capacitor and it is actually a piezoelectric effect.

An unbalanced power circuit can generate the effect of singing capacitors that, if it is uncontrolled, can induce a vibration overlapping the gyroscope resonance frequency, thus affecting the performance of the MEMS sensor.

**Figure 18. Deformation of multilayer ceramic chip capacitor affected by electric field**

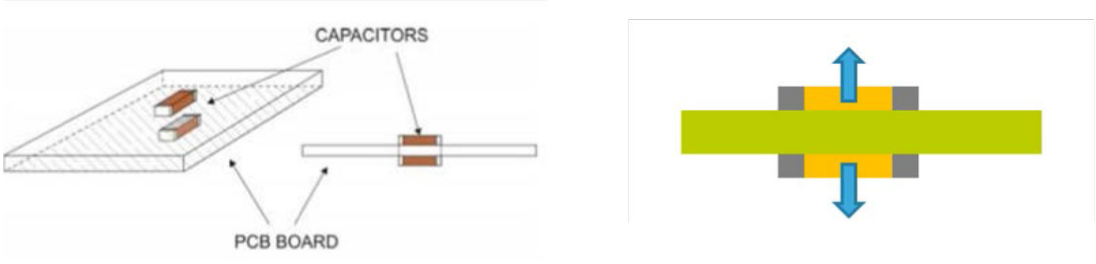


The recommendation is to reduce the effect of singing capacitors by optimizing the PCB layout. In fact, the origin of this effect is the interaction of MLCCs (multilayer ceramic chip capacitors) with the PCB, so optimizing component placement on the PCB can be effective.

Tips:

- PCB material and thickness
  - A thicker PCB is more resistant to deformation and produces a lower sound pressure level (SPL).
- PCB layout
  - MLCCs placed at the edge of the PCB are preferred (lower SPL) with respect to a placement away from the edge of the PCB;
  - When MLCCs are placed symmetrically on each side (opposite sides) of the PCB board (as shown in the figure below), MLCCs tend to cancel out each other’s vibrations.

**Figure 19. Placement of MLCCs to avoid vibration**



*Capacitors on each side of a PCB to create vibration cancellation*

*If the combination of tension applied to the MLCCs is such that a destructive interference is produced, the singing capacitors effect can be avoided.*

## 4.10 Application hints - reference designs of communication protocols and options for positioning primary and redundant sensors

**Figure 20.** Reference design of ASM330LHB - SPI4 communication protocol

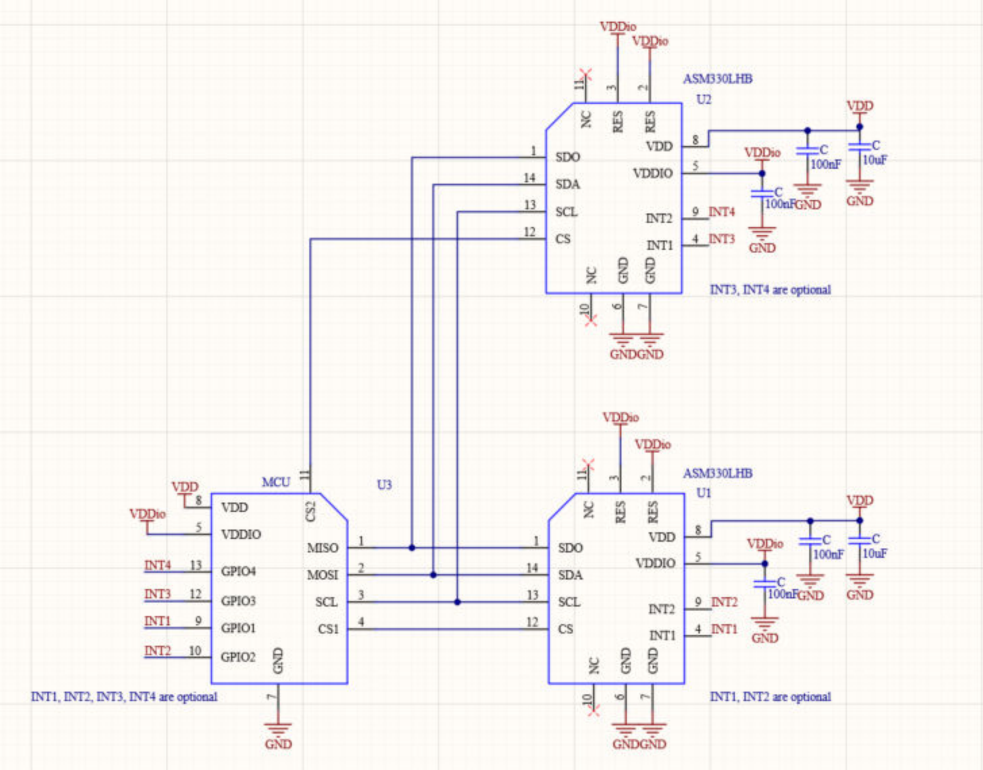
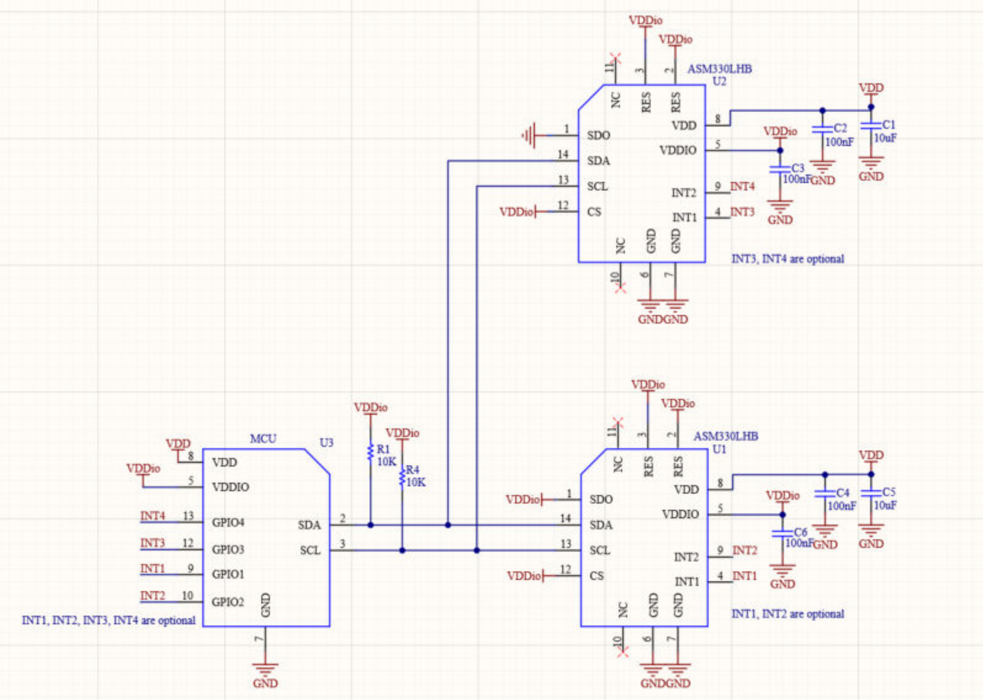


**Figure 21.** Reference design of ASM330LHB - I²C/I3C communication protocol



### Diagrams for ASM330LHB - positioning of primary and redundant sensors

#### Recommended options

Figure 22. Option 1: Z-axis 90° clockwise rotation

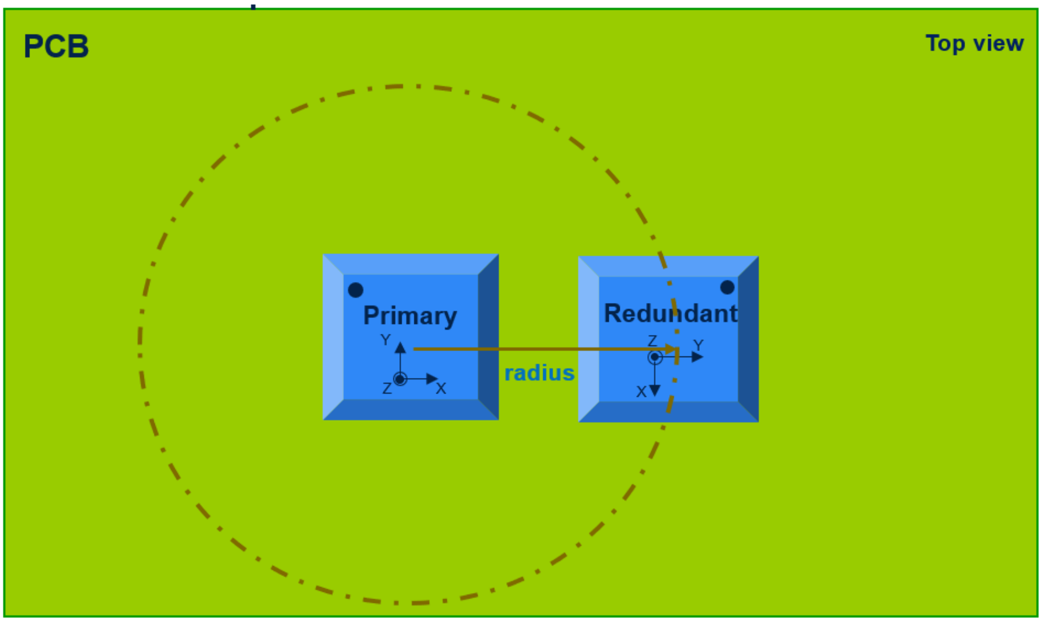


Figure 23. Option 2: Z-axis 270° clockwise rotation

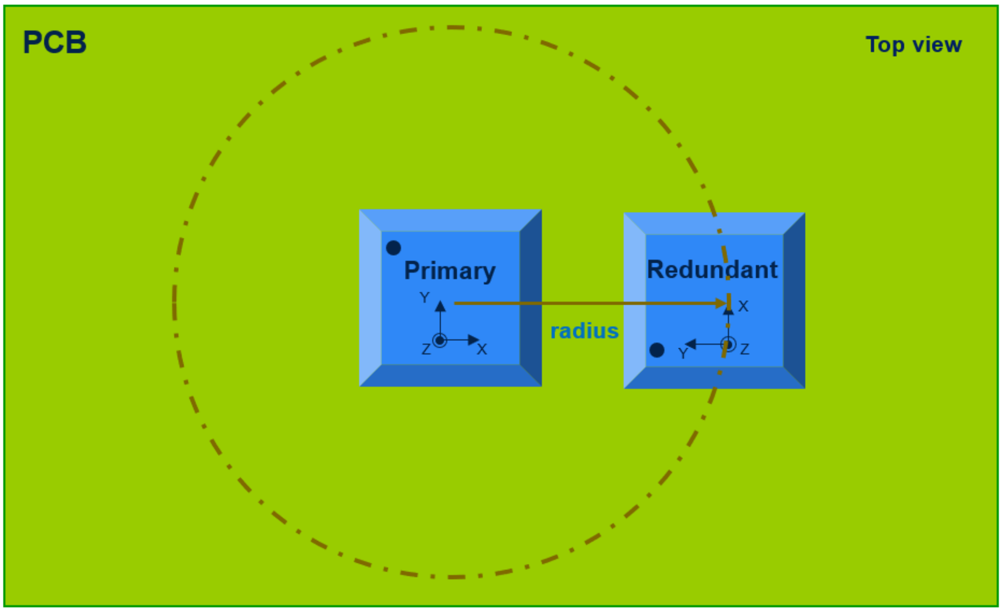
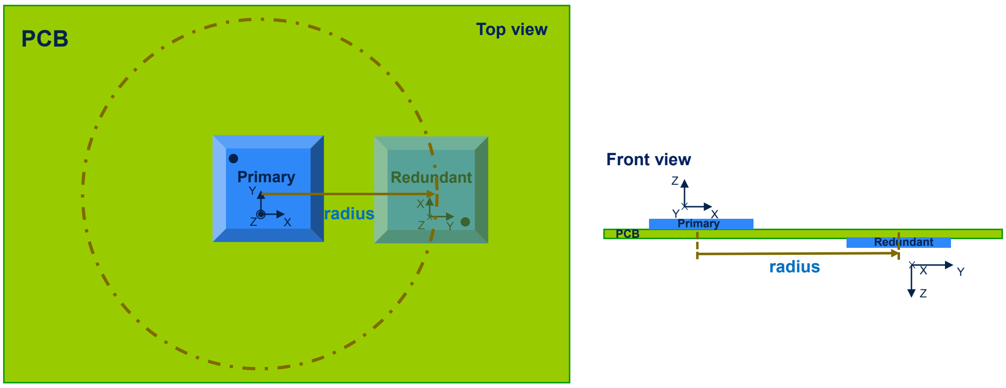


Figure 24. **Option 3: Y-axis 180° clockwise rotation and Z-axis 90° clockwise rotation**



The distance between the center of the primary sensor and the center of the redundant sensor is the radius of the shown **circumference**, in which the center is occupied by the center of the primary sensor and where the center of the redundant sensor can be placed at any point lying on this circumference. The recommended **radius** of this circumference is 2 cm.

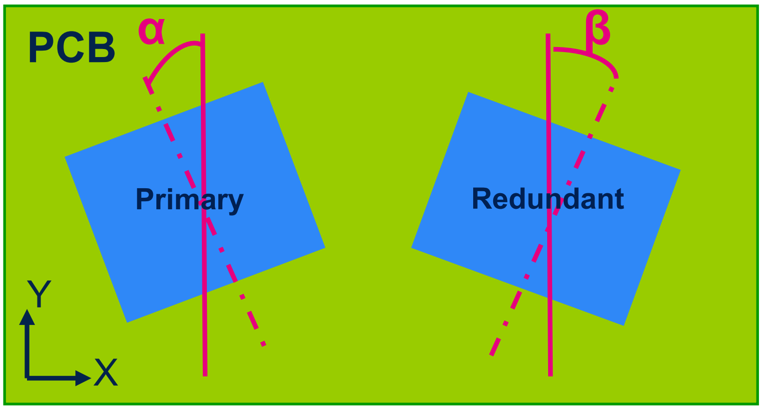
Note that the primary sensor is the one using the ENU coordinate system.

The relative distance between the primary and redundant sensors is the relevant distance, not their absolute position.

The orthogonality error between the primary and redundant sensors is expressed in terms of an angle ($\vartheta$) that must be lower than 3° in order for the software library to work properly: $\vartheta < 3°$

The maximum $\vartheta max = 3°$ angle is obtained in the specific case, which is shown in the following figure.

Figure 25. **Orthogonality error between primary and redundant sensors**



The worst misalignment case between the primary and redundant sensors is shown in Figure 25: $\alpha + \beta = \vartheta max$

The primary and redundant sensors must be positioned so that they do not overlap.

## Revision history

Table 1. **Document revision history**

| Date | Version | Changes |
|---|---|---|
| 25-Aug-2023 | 1 | Initial release |

# Contents

1 Getting the best performance from MEMS devices . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .2
2 Effects of thermomechanical stress . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .3
  2.1 Soldering effect on the MEMS . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 3
  2.2 Effect of thermomechanical offset drift on the sensor . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 4
  2.3 Effect of thermomechanical stress: elastic vs. plastic . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 4
  2.4 Mechanical stress factors . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 5
3 Importance of a good layout . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .6
  3.1 PCB design rules for the footprint . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 6
  3.2 PCB design rules for the traces . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 7
  3.3 Placement rules for the top side . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 8
  3.4 Placement rules for the bottom side . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 8
  3.5 LGA package layout hints - extra tips . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 9
4 Placement considerations for inertial MEMS sensors on the PCB . . . . . . . . . . . . . . . . . . .10
  4.1 Mechanical stress and layout tips . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 10
  4.2 Fasteners on the PCB . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 10
  4.3 Areas of stress on the PCB . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 11
  4.4 Recommended placement of a heat source with respect to the MEMS sensor . . . . . . . . . . 12
  4.5 External loads/forces . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 13
  4.6 Example of shield placement . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 14
  4.7 Findings of shield mounting . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 14
  4.8 Solder profile according to IPC/JEDEC J-STD-020D . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 15
  4.9 Avoiding the effect of singing capacitors on the performance of the MEMS sensor . . . . . . . 17
  4.10 Application hints - reference designs of communication protocols and options for positioning primary and redundant sensors . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 18
Revision history . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .21
List of figures. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .23

# List of figures

**Figure 1.** Consequences of thermomechanical stress . . . 3
**Figure 2.** Offset drift resulting from thermomechanical stress . . . 4
**Figure 3.** Footprint design rules . . . 6
**Figure 4.** Correct traces. . . . 7
**Figure 5.** Examples of top side placement . . . 8
**Figure 6.** Examples of bottom side placement . . . 8
**Figure 7.** Example of incorrect layout from real case . . . 9
**Figure 8.** Placement of sensor between fasteners. . . . 10
**Figure 9.** Placement of sensor in area without vibrations . . . 11
**Figure 10.** Examples of sources of stress to the sensor . . . 12
**Figure 11.** Placement of the heat source far from the MEMS sensor . . . 12
**Figure 12.** Placement of sensor far from external point of force . . . 13
**Figure 13.** Example of shield placement . . . 14
**Figure 14.** Areas of measurement of radius of curvature . . . 14
**Figure 15.** Classification reflow profile for SMT components. . . . 15
**Figure 16.** Classification reflow profiles and temperature . . . 15
**Figure 17.** Classification wave soldering profile for THT components . . . 16
**Figure 18.** Deformation of multilayer ceramic chip capacitor affected by electric field. . . . 17
**Figure 19.** Placement of MLCCs to avoid vibration . . . 17
**Figure 20.** Reference design of ASM330LHB - SPI4 communication protocol. . . . 18
**Figure 21.** Reference design of ASM330LHB - I²C/I3C communication protocol . . . 18
**Figure 22.** Option 1: Z-axis 90° clockwise rotation . . . 19
**Figure 23.** Option 2: Z-axis 270° clockwise rotation. . . . 19
**Figure 24.** Option 3: Y-axis 180° clockwise rotation and Z-axis 90° clockwise rotation . . . 20
**Figure 25.** Orthogonality error between primary and redundant sensors . . . 20

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