TDK IMU Devices
PCB Design Guidelines
For ICM-40607x, ICM-40608, ICM-42xxx, ICM-43xxx, and ICM-45xxx Products

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Document Number: AN-000262
Revision: 1.3
Date: 03/23/2022

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1 INTRODUCTION

This document provides high-level placement and layout guidelines for TDK IMU devices, which may incorporate a combination of gyroscope and accelerometer. Each sensor has specific requirements to ensure the highest performance in a finished product. For a layout assessment of your design, including placement and estimated temperature disturbances, please contact TDK.

TDK IMU Devices discussed in this document (ICM-40607x, ICM-40608, ICM-42xxx, ICM-43xxx, and ICM-45xxx products) consist of 3-axis MEMS gyroscopes and 3-axis MEMS accelerometers.

Please refer to MEMS Handling Application Note (AN-IVS-0002A-00) for additional PCB design guidelines.

2 ACCELEROMETER AND GYROSCOPE PCB BOARD DESIGN GUIDELINES

2.1. PACKAGE STRESS

MEMS accelerometer and gyroscope motion processors are mechanical devices and are affected by package stress. Bending the PCB due to mounting locations, screw holes, or PCB overheating will transfer board stress to the package and can alter the output of the IMU, or in extreme cases, may even damage the MEMS structure.

The IMU should be placed in a location where there will be minimal board stress. Typically, this is away from any fixed mounting location, screw hole, or large insertion components, such as buttons, shielding boxes, connectors, etc. During the design phase, the estimated misalignment, mounting method, and board geometry may be used to determine the areas that have the least internal stress, through static or finite element analysis.

Package stress can also be introduced from thermal sources during soldering or reflow processes. Uneven thermal expansion and cooling during the assembly process introduces this stress. Exceeding the conditions in the reflow diagram provided in the MEMS Handling Application Note (AN-IVS-0002A-00) is not recommended.

Hand soldering the IMU is not recommended, as the uneven application of heat during soldering may introduce an undesired bias offset in the part. Uneven solder on each pin, may also lead to package stress that may affect the data output. Do not place any component pads or vias close to the package land area, to ensure even cooling and minimal mechanical coupling between the IMU and adjacent devices.

Epoxy-seal can bring mechanical stress to IMU. It is prohibited. Any epoxy-sealed parts on the board should be placed away from the IMU such that the epoxy resin does not contact with the package. Curing shrinkage or uneven thermal expansion may introduce package stress and adversely affect the sensor output.

Keep the IMU away from the edge of the PCB or bridges for PCB separation by router (Figure 1). Deflection from a routing drill or saw can damage the MEMS device. Similarly, dull router bits and saw blades can cause excessive mechanical vibration, which should be avoided. Do not snap apart panelized boards, since snapping apart the PCB boards may introduce severe bending forces and mechanical shock, which may damage the IMU.

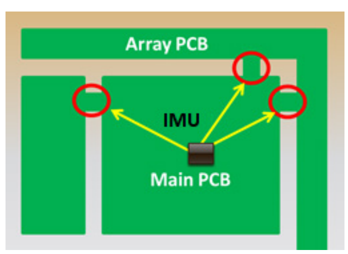


Figure 1. Panelized PCB Bridges

Do not place connectors or test points for Pogo pins on the PCB surface below the IMU location, as in Figure 2 Deflection and shock from snapping the connectors and pressure from the Pogo pin during functional test on a production line may damage the MEMS part.

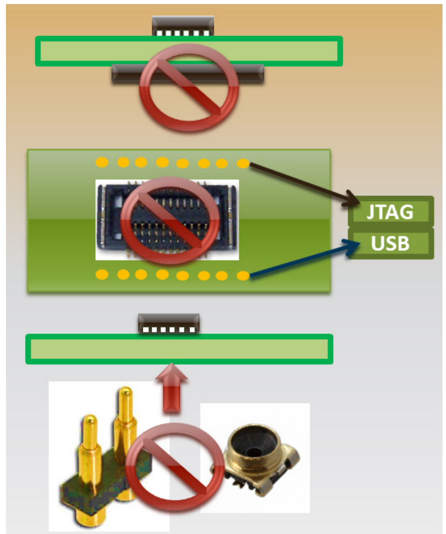


Figure 2. Avoid connectors directly behind the board

2.2. SHOCK AND VIBRATION

The MEMS device can be damaged when shock level is over datasheet specification. Shock or impact should be avoided in manufacturing flow or device assembly process.

During the design phase the IMU should be placed in the location where it will receive the least amount of shock possible. Various measurements can be taken to reduce shock transfer, such as location of the IMU, shock absorbing washers/gaskets for screw points, and shock absorbing foam pads. From a systems level, the placement of other PCBs/Modules/Sub-systems should be placed away from the top/bottom of where the IMU is located, to prevent possible contact.

If there are concerns regarding a system level design, the systems should be tested with the IMU as a whole system or tested beforehand and double checked to ensure there is no damage to the IMU.

MEMS gyro and accel have multiple internal resonance points. System level designs should avoid vibrations with the same frequency of IMU resonances. Please consult TDK technical support for each device’s resonant frequency.

The ICM-40607x, ICM-40608, ICM-42xxx, ICM-43xxx, and ICM-45xxx gyroscope sensors operate at specific drive frequencies. Please refer to each part’s datasheet for the exact drive frequency number. Any vibration within these frequency ranges will cause extra gyro noise or even damage the gyro.

The most common PCB board level vibration source is from power circuits such as a wireless charger, and buck and boost power regulation circuits. Powered devices that may generate acceleration or vibration to the MEMS structures can cause damage to MEMS devices. Examples of such components are inductors, capacitors, PMIC, haptic motors, speakers, etc.

The shock experienced from a PCB level versus device level may and will be different. In order to attain the most accurate data reading, the measurements should be taken from a PCB level as close to the IMU as possible. If there is a source of acceleration or vibration in the vicinity of the MEMS device, we recommend testing on the PCB with a vibrometer to confirm that the MEMS device is not being excited by any resonance frequency.

2.3. THERMAL REQUIREMENTS

The internal measurement of the MEMS sensor is dependent on temperature. For TDK IMU devices, temperature compensation is available. However, variations in device temperature may cause changes in sensor accuracy and should be avoided. Consideration should be taken for placement of the IMU relative to heat sources, which may include processors, power management circuitry, or high current devices. The temperature gradient across the IMU should be minimized for best results.

Any unenven temperature between the top and bottom of the IMU can create out of spec sensor offset. Any heat shock (sudden temperature change) can generate unwanted big sensor output. Avoid placing a big heat variation part on the bottom side of the IMU. For example, a wifi chip, AP processor, and so on.

2.4. NOISE SOURCES

Physical noise sources can cause unnecessary vibration and contaminate the desired measurement. The IMU should be mounted in a rigid location that will have minimal external vibration.

Moving parts that cause vibration and are not intended to be measured, such as speakers, vibration/haptic motors, buttons, etc. (Figure 4), should be mechanically isolated from the IMU.

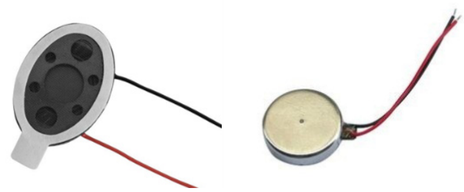


Figure 3. Speaker and Tactile Vibrations can be interpreted as Noise by the IMU

Active signals may harmonically couple with the gyro MEMS devices, compromising gyro response. TDK IMU gyroscopic sensors operate at drive frequencies 25 kHz ~ 29 kHz. To avoid harmonic coupling don't route active signals directly below or near the package. If the IMU device is stacked under an adjacent PCB board, design a ground plane to shield the IMU from the adjacent PCB.

Electrical sources, such as a switched-mode power supply (SMPS) as shown in Figure 5, can cause high frequency vibration. SMPS (switched mode power supply) with switching noise below 150 kHz (including Harmonics) can reduce device performance.

As mentioned in section 2.2, in addition to unwanted IMU vibration output, mechanic vibration can damage MEMS if the vibration frequency matches the MEMS resonant frequency.

Place any acceleration or vibration sources as far away as possible from MEMS devices. If placement is uncertain, consult the local FAE to provide a more detailed analysis.

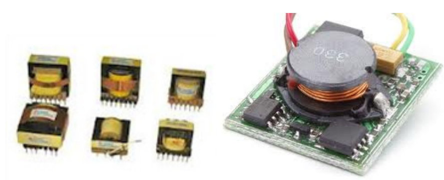


Figure 4. Avoid Switched-Mode Power Supply Circuitry

2.5. PCB FOOTPRINT SOLDER MASK

TDK InvenSense recommends designing the PCB pad layout with Non-Solder Mask Defined pads (NSMD), rather than Solder Mask Defined (SMD) pads. NSMD contact pads have the solder mask pulled away from the solderable metallization. NSMD contact pads have several advantages over SMD pads. They provide a tighter tolerance for copper etching, provide a larger copper pad area, and allow the solder to anchor to the edges of the copper pads, which improves solder joint reliability.

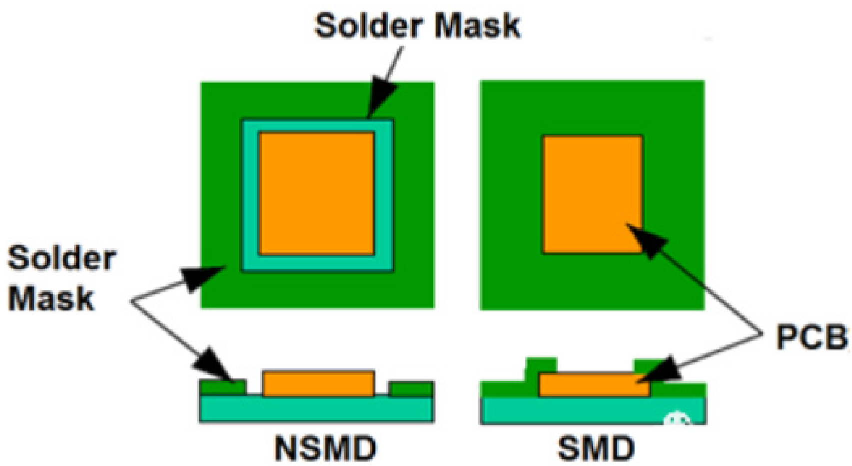


Figure 5. NSMD and SMD

To achieve optimal performance of MEMS motion devices, placing the solder mask below the MEMS component is not recommended. If this is not possible, placing the solder mask below the component will still work.

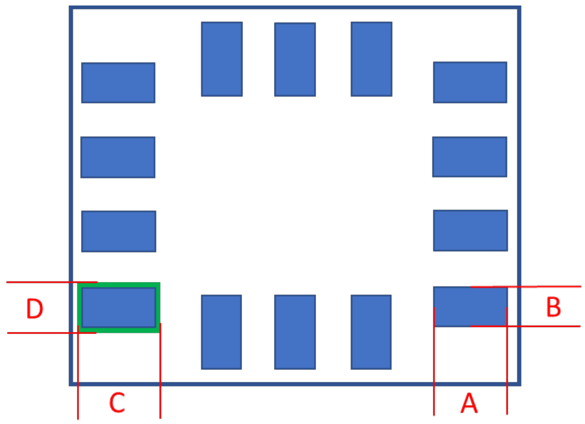
2.6. PCB TRACE LAYOUT AND COMPONENT PCB FOOTPRINT

Traces connected to pads should be as symmetrical as possible. Symmetry and balance for pad traces will improve component self-alignment and lead to better control of solder paste reduction after the reflow process.

For high-speed interfaces, such as I^2C, I3C and SPI, all clock and data traces should be routed with the same length, and away from other high-speed traces. Power traces should also be routed away from high-speed signals.

We recommend 6mil or thicker traces for a 0.5 oz copper PCB. Provide a solid ground return path, with traces 10mil or thicker for a 0.5 oz copper PCB. Do not use small vias for power and GND traces.

The PCB Layout Diagram and recommended pad size is provided within the IMU device datasheets. Figure 3 provides an example of a PCB Layout Diagram for ICM-40607x, ICM-40608, ICM-42xxx, ICM-43xxx, and ICM-45xxx products. Please use the most recent revision of the datasheet for the device that you are working with. Dummy traces can be added on unused pins.



- A = PCB land length = LGA solder pin length
- B = PCB land width = LGA solder pin width
- C = Solder mask opening length = PCB land length + 0.1 mm
- D = Solder mask opening width = PCB land width + 0.1 mm

Figure 6. Recommended PCB Layout footprint for the ICM-40607x, ICM-40608, ICM-42xxx, ICM-43xxx, and ICM-45xxx devices

Trace, via, and filled copper are not allowed under the IMU chip directly, as they can cause elevation changes.

Do not place vias within the pad outline because vias and their related plating materials can contribute to an orientation offset and non-uniform mechanical package stress.

NC (No Connect) pins should be soldered to the board for mechanical stability, but those pads on the board should not be connected electrically.

2.7. PCB DESIGN IMPORTANT NOTES

Always consider the items below when doing PCB design.

- Always place VDD decoupling capacitors as close as possible to the VDD pin. The VDD pin fanout trace should be thicker than 6 mil. The noise level on the VDD must meet datasheet specifications.
- Always place VDDIO decoupling capacitors as close as possible to the VDDIO pin. The VDDIO pin fanout trace should be thicker than 6 mil.
- VDD and VDDIO can be from same power supply source, but each should have its own decoupling capacitor.
- Provide solid GND connections for GND pin (pin6). Any nearby GND via must be bigger than 8 mil drill and 12 mil copper. Multiple nearby GND vias are recommended for solid GND connections. The GND pin fanout trace should be thicker than 6 mil.
- Minimize noise on digital communication bus, I^2C, I3C, and SPI. Their noise level (overshoot and undershoot) must meet datasheet specifications. For SDA/SDIO/SDI, SLC/SCLK and /CS input signals, the Vih must be bigger than 0.7*VDDIO and the Vil must be lower than 0.3*VDDIO. Any specification violation will cause communication errors.
- Reduce serial communication bus capacitance by avoiding long trace. Always balance the bus lines as close as possible to trace length.
- ICM-40607x, ICM-40608, ICM-42xxx, ICM-43xxx, and ICM-45xxx provide configurations for output pad slew rate (drive strength) adjustment. User can adjust the output pad slew rate to optimize signal integrity on PCB board. Stronger drive strength is recommended for long PCB trace or long jump wire connections. Do not apply unnecessary strong drive strength to avoid over/under shoot on signal. We recommend adjusting the slew rate setting by using scope to monitor the signals.

- Keep VDD, VDDIO, serial communication lines away from any battery charge and DC-DC switching power regulator related components and signals when doing the layout. The high energy of a power signal can generate a lot of noise.

2.8. FLEX PCB

Flex PCB should be avoided for MEMS sensor parts. If flex PCB must be used, a stiffner must be provided on the opposite side of the flex PCB. The thickness of the stiffner depends on its material. The goal is to prevent the flex PCB from bending, which will generate mechanical stress to MEMS.

3 ASSEMBLY PRECAUTIONS

3.1. SOLDER PASTE STENCIL

The TDK InvenSense IMU components mentioned in this document have an industry standard 14 pin LGA package with the size of 2.5 mm x 3 mm. Please follow industry standard generic rules to build solder paste stencil during the surface mount process. For example, the aspect ratio should be bigger than 1.5 and the area ratio should be bigger than 0.66.

3.2. MEMS HANDLING AND ASSEMBLY GUIDE

Do not clean MEMS devices in an ultrasonic bath. Ultrasonic baths can induce MEMS damage if the bath energy causes excessive drive motion through resonant frequency coupling.

Please refer to MEMS Handling Application Note (AN-IVS-0002A-00) for additional information.

3.3. GYROSCOPE SURFACE MOUNT GUIDELINES

TDK MEMS gyroscopes sense rate of rotation and mechanical stress coming from the PCB board. This board stress can be minimized by adhering to certain design rules:

When using MEMS gyroscope components in plastic package devices, PCB mounting and assembly can cause package stress. This package stress in turn can affect the output offset and its value over a wide range of temperatures. This stress is caused by the mismatch between the Coefficient of Linear Thermal Expansion (CTE) of the package material and the PCB. Care must be taken to avoid package stress due to mounting.

Traces connected to pads should be as symmetrical as possible. Maximizing symmetry and balance for pad connection will help component self-alignment and will lead to better control of solder paste reduction after reflowing.

Any material used in the surface mount assembly process of the MEMS gyroscope should be free of restricted RoHS elements or compounds. Pb-free solders should be used for assembly.

4 ANALYZING SENSOR DATA ISSUES DUE TO SENSOR PLACEMENT

4.1. OVERVIEW

As stated in the previous sections, sensor data will be affected by the location of the device and its surrounding components. This section describes the tools that can be used to analyze the sensor data and to characterize and correct issues of magnetic distortion, package stress, noise, and thermal conditions. TDK recommends contacting the local TDK support team when the need to characterize devices using TDK IMUs arises.

4.2. ANALYZING SENSOR DATA

When possible, the orientation of the device should be analyzed simultaneously to characterize sensor angular accuracy.

4.2.1. TDK sensor test tools

TDK software releases are packaged with test tools that provide the capability to collect sensor data at run-time. Using the test tools provided by TDK to first verify if the sensor is responding correctly and the sensor data is within spec is recommended. Analyzing run-time sensor data will help detect problems with sensor performance.

4.2.2. Third party sensor tools

Third party tools such as Microsoft's Sensor Diagnostic Tool or Traceview can be also used to collect run-time sensor data to detect problems with sensor performance. These tools provide capabilities to save the individual accelerometer and gyroscope to a comma separated (CSV) file. The CSV data can be analyzed, and sensor data can be graphed to detect placement-related problems.

4.2.3. Sensor data collection

TDK software has the capability to log sensor data to a file during device operation. The software provides the capability to collect raw as well as calibrated sensor data. This gives user the option to replay the sensor data later and detect any errors due to placement issues.

Sensor data collected in this fashion can be post-processed using mathematical analysis software to detect the effects of magnetic distortion, package stress, noise, and thermal conditions, and assist in mitigation of those effects.

5 REVISION HISTORY

REVISION DATE	REVISION	DESCRIPTION
03/01/2021	1.0	Initial release
11/09/2021	1.1	Added section 3.1 Updated section 2.2
01/05/2022	1.2	Added section 2.5 and 3.1 Rearranged some sections
03/23/2022	1.3	Added output pad slew rate in section 2.7