Understanding IMU Sensor Offset

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1 INTRODUCTION

Physical properties of MEMS structures and CMOS die are not perfect because of fabrication variations in the silicon die and package stresses. The effects manifest as offset when the sensor is stationery and result in inaccurate motion sensing. When a gyro is stationary, the unwanted non-zero output is gyro offset. When there is no linear acceleration, the accel output is accel offset.

The offset affects sensor data integration result directly. The small amount of error from the offset can accumulate to become a bigger error. Most of applications need offset calibration.

This document will explain the details of sensor offset, which are very important to understand.

2 PART LEVEL OFFSET VS. BOARD LEVEL OFFSET

2.1 PART LEVEL OFFSET

When the part is not soldered to the PCB board, the offset value measured is part level offset. This offset reflects part silicon variation and asymmetrical part packaging. Most IMU products have this offset value in the datasheet.

2.2 BOARD LEVEL OFFSET

After the part has been soldered to the PCB board, sensor offset will be changed from its part level value. The change is caused by soldering asymmetry and PCB board mechanical stress under different temperatures and other conditions such as tightening mounting screws, and so on.

2.3 TDK IMU BOARD LEVEL OFFSET IN DATASHEET

TDK includes sensor board level offset in some product datasheets. The board level offset is measured using a special setup which includes PCB and aluminium PCB support base. Figure 1 shows this measurement setup.

Most user products have different board structures and thickness than this setup. In such cases, you should not apply the TDK datasheet value to your product directly. Some adjustment calculations are needed.

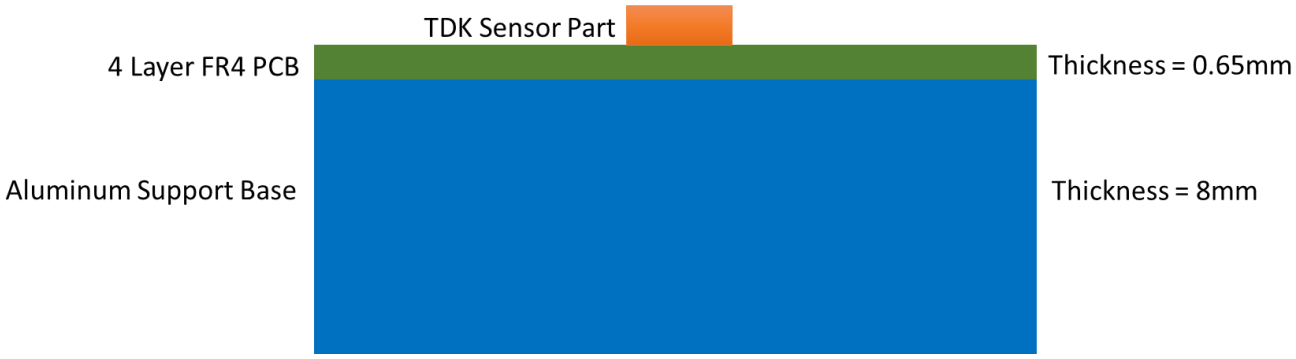

Figure 1. TDK board level sensor offset test platform

3 BOARD LEVEL OFFSET CONSIDERATION

Sensor output measured by the end user of the production device is board level offset, which is more than just part level offset. It is the cumulative effect of offset, sensitivity, temperature variations, local variations (PCB bending, misalignment), etc.

There are two popular offset calculation methods.

3.1 DEVICE OFFSET CALCULATION

3.1.1 Maximum Sum Method

Maximum sum method is mostly used in consumer products.

User production device offset specification should be

$$\text{Device offset} = \pm(\text{Total offset} + \text{BoardVar}) * (1 + \text{Total sensitivity})$$

Equation 1. Maximum Sum Calculation

In Equation 1:

- Total offset = (Initial offset + Offset over Temperature)
  - Offset over temperature = TCO*TempVar (temperature variance)
- BoardVar = Variation from PCB board mechanical stress and part assembly. Derived on a case-by-case basis from user product setup.
- Total sensitivity = (Initial sensitivity + sensitivity over Temperature)
  - Sensitivity over temperature = TCS*TempVar (temperature variance)
  -

3.1.2 Root Sum Squared Method

Root sum squared method is used in automotive and machinery industry mostly.

$$\text{Product offset} = \pm\text{sqrt}\left((\text{initial offset})^2+(\text{offset over T})^2+(\text{Others})^2 \right)*(1+\text{Total sensitivity})$$

Equation 2. Root Sum Squared Calculation

In Equation 2:

- Initial offset = IMU sensor initial offset.
- Offset over T = Offset over temperature = TCO*TempVar (temperature variance)
- Others includes
  - BoardVar = Variation from PCB board mechanical stress and part assembly. Derived on a case-by-case basis from user product setup.
- Total sensitivity = (Initial sensitivity + sensitivity over Temperature)
  - Sensitivity over temperature = TCS*TempVar (temperature variance)

3.2 OFFSET CALCULATION EXAMPLE

ICM-45631 gyro will be used for this calculation example.

From the ICM-45631 DS, Gyro max spec: Offset = ±3 dps, TCO = ±0.02 dps/°C, TCS = ±0.02%/°C, Initial sensitivity_Error = ±1%.

User environment assumptions: Assume “BoardVar” = ±3dps; TempVar = 40°C

3.2.1 Maximum Sum Method Example

Example user production device offset spec:

- Initial offset = 3 dps; Offset over temperature = 0.02*40 = 0.8 dps
- BoardVar = 3 dps

- Initial sensitivity error = 1%; Sensitivity error over temperature = 0.02*40 = 0.8%
- Total offset = (3 + 0.8 + 3)*(1 + 1% + 0.8%) = 6.8 * 1.018 = 6.92 dps

3.2.2 Root Sum Squared Method Example

Example user production device offset spec:

- Initial offset = 3 dps; Offset over temperature = 0.02*40 = 0.8 dps
- Others (BoardVar) = 3 dps
- Initial sensitivity error = 1%; Sensitivity error over temperature = 0.02*40 = 0.8%
- Total offset = sqrt ($(3)^2 + (0.8)^2 + (3)^2$)*(1 + 1% + 0.8%) = 4.39 dps

4 DETERMINING YOUR SENSOR OFFSET

If an assembled device shows out-of-spec offset initially, we recommend running a power cycle test 5 times on this device. Devices that still show out-of-spec offset should be further debugged and may be considered for possible failure analysis.

5 REVISION HISTORY

REVISION DATE	REVISION	DESCRIPTION
12/16/2020	1.0	Initial Release
03/19/2021	1.1	Added root sum squared calculation method
05/21/2021	1.2	Fixed a typo.
03/16/2023	1.3	1) removed HTOL 2) changed calculation example from ICM-42686-P to ICM-45631 3) updated chapter 4

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