IAM-20680xx, IAM-20380xx, IAM-20381xx Accel and Gyro Self-Test Implementation

InvenSense, Inc. reserves the right to change specifications and information herein without notice unless the product is in mass production and the application note has been designated by InvenSense in writing as subject to a specified Product / Process Change Notification Method regulation.

InvenSense, a TDK Group Company
1745 Technology Drive, San Jose, CA 95110 U.S.A
+1(408) 988–7339
invensense.tdk.com

Document Number: AN-000143
Revision: 5.0
Rev Date: 07/31/2023

TABLE OF CONTENTS

1 PURPOSE

This document explains the gyroscope and accelerometer Self-Test implementation for the IAM-20680xx 6-axis, IAM-20380xx 3-axis and IAM-20381xx 3-axis product family. Settings and procedures are common for both 3 and 6 axis families; when using a 3-axis product, only the information referred to the implemented sensor (either gyroscope or accelerometer) is valid. Refer to datasheet for register definition and addresses.

2 SELF-TEST OVERVIEW

Gyroscope and accelerometer Self-Test procedure enable customers to perform a functional test of the mechanical and electrical integrity of TDK-InvenSense sensors without requiring physical device movement.

When the Self-Test is activated, on-chip electronics actuate the MEMS device. This actuation moves the sensor masses equivalent to a pre-defined motion. This proof mass displacement results in a change of sensor output and is reflected in the output signal.

A customer runs Self-Test software in their factory and compares the output value against the value stored on chip during TDK-InvenSense's component production test.

2.1 GYROSCOPE SELF-TEST OVERVIEW

The gyroscope Self-Test response (STR) is defined as follows:

$$Self\text{-}Test\ \ Response = Gyroscope\ Output\ with\ Self\text{-}Test\ Enabled - Gyroscope\ Output\ with\ Self\text{-}Test\ Disabled$$

This Self-Test-response is used to determine whether the part has passed or failed Self-Test by finding the change from factory trim of the Self-Test response as follows:

$$Change\ from\ Factory\ Trim\ of\ the\ Self\text{-}Test\ Response(\%) = \frac{(STR - FT)}{FT}$$

where:

$$FT = Factory\ Trim\ Value\ of\ Self\text{-}Test\ \ Response$$

If the customer's gyroscope Self-Test response is within limits as defined in Section 3, then Self-Test has passed, and the component is deemed functional.

2.2 ACCELEROMETER SELF-TEST OVERVIEW

The accelerometer Self-Test response (STR) is defined as follows:

$$Self\text{-}Test\ \ Response = Accelerometer\ Output\ with\ Self\text{-}Test\ Enabled - Accelerometer\ Output\ with\ Self\text{-}Test\ Disabled$$

This Self-Test-response is used to determine whether the part has passed or failed Self-Test by finding the change from factory trim of the Self-Test response as follows:

$$Change\ from\ Factory\ Trim\ of\ the\ Self\text{-}Test\ Response(\%) = \frac{(STR - FT)}{FT}$$

Where:

$$FT = Factory\ Trim\ Value\ of\ Self\text{-}Test\ \ Response$$

If the customer's accelerometer Self-Test response is within limits as defined in Section 3, then Self-Test has passed, and the component is deemed functional.

2.3 SELF-TEST PROCEDURE OVERVIEW

For gyroscope, the procedure starts by measuring the digital output of the three gyroscopes axes and records them as GX_OS, GY_OS, and GZ_OS. The next step is to enable the Self-Test mode for all gyroscope axes and measure the three digital outputs, recording them as GX_ST_OS, GY_ST_OS, and GZ_ST_OS.

The Self-Test response values are then reported as:

- GX_ST = GX_ST_OS - GX_OS
- GY_ST = GY_ST_OS - GY_OS
- GZ_ST = GZ_ST_OS - GZ_OS

Similarly, for the accelerometer, the reported Self-Test response are:

- AX_ST = AX_ST_OS - AX_OS
- AY_ST = AY_ST_OS - AY_OS
- AZ_ST = AZ_ST_OS - AZ_OS

3 SELF-TEST DETAILED PROCEDURE

Self-Test expects the device to be stationary and performed at room temperature, 25°C.

The device will fail gyroscope Self-Test if it rotates during the test. Note that gyro Self-Test might pass if it experiences a constant rotation during the two measurements, but this is not guaranteed.

Similarly, to maintain accuracy during the accelerometer Self-Test, changes in both linear velocity and tilt angle should be avoided during the measurement.

3.1 CONFIGURATION SAVE/RESTORE

If accelerometer and gyroscope settings need to be restored after running Self-Test, the following register content needs to be saved before starting Self-Test and restored after Self-Test:

- INT_ENABLE (0x38)
- FIFO_EN (0x23)
- USER_CTRL (0x6A)
- CONFIG (0x1A)
- GYRO_CONFIG (0x1B)
- ACCEL_CONFIG (0x1C)
- ACCEL_CONFIG2 (0x1D)
- SMPLRT_DIV (0x19)
- LP_MODE_CFG (0x1E)
- PWR_MGMT_2 (0x6C)

3.2 SELF-TEST SETTINGS

Accelerometer and Gyroscope must both be in Low Noise mode:

- Set PWR_MGMT_2 register, address 0x6C to 0x00 (to enable accelerometer and gyroscope)
- Wait 50 ms
- Set LP_MODE_CONFIG register, address 0x1E to 0x00 (Gyroscope LN mode)
- Set SMPLRT_DIV register, address 0x19 to 0x00 (to set 1 kHz ODR)
- Wait 50 ms

3.2.1 Gyroscope

Change the digital low pass filter (DLPF) code to 2 (Register Address 0x1A, Bit [2:0]). The following table details the configuration of the component when the DLPF is configured to 2:

DLPF Config	LPF BW	Sampling Rate	Filter Delay
2	92 Hz	1 kHz	3.36 ms

Select a full scale range of ±250 dps by setting the GYRO_FS_SEL[1:0] bits to b00 in register GYRO_CONFIG(Address 0x1B).

3.2.2 Accelerometer

Change the DLPF Code to 2 (Register Address 0x1D, Bit [2:0]). The following table details the configuration of the component when the DLPF is configured to 2:

A_DLPF Config	LPF BW	Sampling Rate	Filter Delay
2	99 Hz	1 kHz	2.88 ms

Select full-scale range of ±2g by setting the ACCEL_FS_SEL[1:0] bits to b00 in register ACCEL_CONFIG (Address 0x1C).

Set register PWR_MGMT_1 (Register Address 0x6B) to 0x01 to set accelerometer low noise mode and select clock source then wait for 20 ms.

3.3 SELF-TEST DATA COLLECTION

User can select to read data from FIFO or registers. Data are read at 1 kHz, and 200 readings must be taken and averaged. Two sets of data are collected, one in normal mode and another in Self-Test mode. This is shown in steps 2 to 5.

1. For FIFO based reads:

   - Set USER_CTRL Register address 0x6A to 0x44 (clears and enables FIFO)
   - Set FIFO_EN Register address 0x23 to 0x78 (Enable accelerometer and gyroscope to write to FIFO)
   - Wait 200 ms (Time required for 200 samples to be accumulated in FIFO)
   - Stop FIFO by setting register FIFO_ENABLE (address 0x23) to 0x00.
   - Read both registers FIFO_COUNTH (address 0x72) and FIFO_COUNTL (address 0x73) to retrieve the number of bytes in FIFO
   - Read FIFO by reading FIFO READ WRITE register (address 0x74) for number of bytes in FIFO

2. For register-based reads:

   - Read the gyroscope and accelerometer output by combining the readings from the OUT_H and OUT_L registers. The output values are 16 bits wide and in 2's complement. Average 200 readings and save the averaged values as GX_OS, GY_OS, GZ_OS, AX_OS, AY_OS and AZ_OS.
     - GX_OS = Average (GYRO_XOUT_H << 8| GYRO_XOUT_L)
     - GY_OS = Average (GYRO_YOUT_H << 8| GYRO_YOUT_L)
     - GZ_OS = Average (GYRO_ZOUT_H << 8| GYRO_ZOUT_L)
     - AX_OS = Average (ACCEL_XOUT_H << 8| ACCEL_XOUT_L)
     - AY_OS = Average (ACCEL_YOUT_H << 8| ACCEL_YOUT_L)
     - AZ_OS = Average (ACCEL_ZOUT_H << 8| ACCEL_ZOUT_L)

     Here is address of the output registers:

Addr (Hex)	Addr (Dec.)	Register Name	Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
3B	59	ACCEL_XOUT_H	ACCEL_XOUT_H[15:8]							
3C	60	ACCEL_XOUT_L	ACCEL_XOUT_L[7:0]							
3D	61	ACCEL_YOUT_H	ACCEL_YOUT_H[15:8]							
3E	62	ACCEL_YOUT_L	ACCEL_YOUT_L[7:0]							
3F	63	ACCEL_ZOUT_H	ACCEL_ZOUT_H[15:8]							
40	64	ACCEL_ZOUT_L	ACCEL_ZOUT_L[7:0]							
43	67	GYRO_XOUT_H	GYRO_XOUT[15:8]							
44	68	GYRO_XOUT_L	GYRO_XOUT[7:0]							
45	69	GYRO_YOUT_H	GYRO_YOUT[15:8]							
46	70	GYRO_YOUT_L	GYRO_YOUT[7:0]							
47	71	GYRO_ZOUT_H	GYRO_ZOUT[15:8]							
48	72	GYRO_ZOUT_L	GYRO_ZOUT[7:0]							

   The readings above are in units of LSBs. Normally these readings would be converted to *º/s* or *g* by dividing the reading with corresponding Sensitivity Scale Factor from the datasheet. However, for purpose of self-test, use these values in units of LSBs without converting to *º/s* or *g*.

3. Self-Test mode enable:

   - Set register: (0x1B) GYRO_CONFIG Bits [7:5], X/Y/ZG_ST to b111 to enable gyroscope Self-Test.
   - Set register: (0x1C) ACCEL_CONFIG Bits [7:5], X/Y/Z_AST to b111 to enable accelerometer Self-Test.

4. Wait 20 ms for outputs to stabilize

5. Read the gyroscope and accelerometer output and average 200 readings. These readings are in units of LSBs. Save the averaged values as GX_ST, GY_ST, GZ_ST, AX_ST, AY_ST and AZ_ST. Reading can be performed from FIFO (refer to point #1) or from registers (refer to point #2).

6. Calculate the Self-Test response as follows:
   - GX_ST = GX_ST_OS - GX_OS
   - GY_ST = GY_ST_OS - GY_OS
   - GZ_ST = GZ_ST_OS - GZ_OS
   - AX_ST = AX_ST_OS - AX_OS
   - AY_ST = AY_ST_OS - AY_OS
   - AZ_ST = AZ_ST_OS - AZ_OS
7. Self-Test mode disable:
   - Set register: (0x1B) GYRO_CONFIG, Bits [7:5], X/Y/ZG_ST to b000 to disable gyroscope Self-Test
   - Set register: (0x1C) ACCEL_CONFIG, Bits [7:5], X/Y/Z_A_ST [0-2] to b000 to disable accelerometer Self-Test
8. Refer to Section 3.1 Configuration Save/Restore for additional configuration restoration.

3.4 SELF-TEST PASS/FAIL CRITERIA

ST_Code is a value that is calculated from actual Self-Test measurements in TDK-InvenSense's factory final test and stored to following user registers:

- Register SELF_TEST_X_GYRO (0x00) contains Gyroscope X Self-Test code: GX_ST_Code
- Register SELF_TEST_Y_GYRO (0x01) contains Gyroscope Y Self-Test code: GY_ST_Code
- Register SELF_TEST_Z_GYRO (0x02) contains Gyroscope Z Self-Test code: GZ_ST_Code
- Register SELF_TEST_X_ACCEL(0x0D) contains Accelerometer X Self-Test code: AX_ST_Code
- Register SELF_TEST_Y_ACCEL(0x0E) contains Accelerometer Y Self-Test code: AY_ST_Code
- Register SELF_TEST_Y_ACCEL(0x0F) contains Accelerometer Z Self-Test code: AZ_ST_Code

Next steps need to be performed to assess self-test procedure result:

1. Retrieve factory Self-Test code (ST_Code) from the registers above and calculate the factory Self-Test values (xx_ST_FV) for each axis of gyroscope and accelerometer using the following equations, where "FS" is the value in lsb of full-scale selection register (FS_SEL for gyroscope and ACCEL_FS_SEL for accelerometer):

$$GX\_ST\_FV = (2620/2^{FS}) * 1.01^{(GX\_ST\_Code-1)} \text{ (lsb)}$$
$$GY\_ST\_FV = (2620/2^{FS}) * 1.01^{(GY\_ST\_Code-1)} \text{ (lsb)}$$
$$GZ\_ST\_FV = (2620/2^{FS}) * 1.01^{(GZ\_ST\_Code-1)} \text{ (lsb)}$$
$$AX\_ST\_FV = (2620/2^{FS}) * 1.01^{(AX\_ST\_Code-1)} \text{ (lsb)}$$
$$AY\_ST\_FV = (2620/2^{FS}) * 1.01^{(AY\_ST\_Code-1)} \text{ (lsb)}$$
$$AZ\_ST\_FV = (2620/2^{FS}) * 1.01^{(AZ\_ST\_Code-1)} \text{ (lsb)}$$

Note: These Self-Test values (xx_ST_FV) are in units of LSBs. The xx_ST_FV values can be stored on host to avoid runtime calculation at every bootup.

2. Determine passing or failing of Self-Test:
   a. Ensure Factory Self-Test values xx_ST_FV ≠ 0, compare the current Self-Test response (GX_ST, GY_ST, GZ_ST, AX_ST, AY_ST, and AZ_ST) to the corresponding factory Self-Test value (xx_ST_FV), and report Self-Test is passing if all the following criteria are fulfilled:

Axis	Pass criteria
X-gyro	(GX_ST / GX_ST_FV) > 0.5
Y-gyro	(GY_ST / GY_ST_FV) > 0.5
Z-gyro	(GZ_ST / GZ_ST_FV) > 0.5
X-Accel	0.5 < (AX_ST / AX_ST_FV) < 1.5
Y-Accel	0.5 < (AY_ST / AY_ST_FV) < 1.5
Z-Accel	0.5 < (AZ_ST / AZ_ST_FV) < 1.5

b. If factory Self-Test values ST_Code=0 for any of X, Y, Z-axis, compare the current Self-Test response (GXST, GYST, GZST, AXST, AYST, and AZST) to the ST absolute limits (ST_AL) and report Self-Test is passing if all the following criteria are fulfilled.

Axis	Pass criteria
X-gyro	|GXST| ≥ 60dps
Y-gyro	|GYST| ≥ 60dps
Z-gyro	|GZST| ≥ 60dps
X-Accel	50mgee ≤ |AXST| ≤ 1200mgee
Y-Accel	50mgee ≤ |AXST| ≤ 1200mgee
Z-Accel	50mgee ≤ |AXST| ≤ 1200mgee

If Self-Test passes criteria (a) and (b), it is necessary to check gyro offset values.

Report passing Self-Test if the following criteria is fulfilled.

Axis	Pass criteria
X-gyro	|GXOFFSET| ≤ 20dps
Y-gyro	|GYOFFSET| ≤ 20dps
Z-gyro	|GZOFFSET| ≤ 20dps

GXOFFSET, GYOFFSET, and GZOFFSET are offset values of gyroscope X, Y, and Z axes.

The self-test pass/fail criteria above are not recommended unless the following conditions can be guaranteed in the production test environment.

Conditions affecting Self-Test pass/fail criteria offset ranges:

- SMT, post SMT relaxation time, and temperature variations may impact the measured offset.
- Gyro and Accel offsets may shift post SMT, depending upon the settling time.
- Production Line Noise - Machine vibrations, production line noise, motors, and other production line equipment, including HVAC units turning on and off may cause the offsets to shift.
- All these conditions in the production environment will further impact self-test outputs.

If any of the conditions above are true, pass/fail criteria offset limits will be wider and can cause false failures.

TDK-InvenSense recommends using ±50% of the Self-Test register values to prevent false failures due to production line conditions impacting the outputs. In general, 50% limits are adequate to catch gross failures, which is the aim of the Self-Test feature.

Please refer to the corresponding device datasheet for information on registers referenced in this document.

4 REVISION HISTORY

Revision Date	Revision	Description
2/7/2017	1.0	Initial release (uncontrolled AN-000xxx IAM-20680 Self-Test Draft)
6/17/2020	2.0	Complete re-write to correct errors
5/10/2022	3.0	Self-Test pass/fail when ST code =0
6/6/2022	4.0	Added missing production environment criteria
7/31/2023	5.0	Added 3-axis products (IAM-20380xx and IAM-20381xx) references in the title and in the text. Typo corrections.

COMPLIANCE DECLARATION DISCLAIMER

TDK-InvenSense believes the environmental and other compliance information given in this document to be correct but cannot guarantee accuracy or completeness. Conformity documents substantiating the specifications and component characteristics are on file. TDK-InvenSense subcontracts manufacturing and the information contained herein is based on data received from vendors and suppliers, which has not been validated by TDK-InvenSense.

This information furnished by TDK-InvenSense or its affiliates ("TDK TDK-InvenSense") is believed to be accurate and reliable. However, no responsibility is assumed by TDK TDK-InvenSense for its use, or for any infringements of patents or other rights of third parties that may result from its use. Specifications are subject to change without notice. TDK TDK-InvenSense reserves the right to make changes to this product, including its circuits and software, in order to improve its design and/or performance, without prior notice. TDK TDK-InvenSense makes no warranties, neither expressed nor implied, regarding the information and specifications contained in this document. TDK TDK-InvenSense assumes no responsibility for any claims or damages arising from information contained in this document, or from the use of products and services detailed therein. This includes, but is not limited to, claims or damages based on the infringement of patents, copyrights, mask work and/or other intellectual property rights.

Certain intellectual property owned by TDK-InvenSense and described in this document is patent protected. No license is granted by implication or otherwise under any patent or patent rights of TDK-InvenSense. This publication supersedes and replaces all information previously supplied. Trademarks that are registered trademarks are the property of their respective companies. TDK TDK-InvenSense sensors should not be used or sold in the development, storage, production or utilization of any conventional or mass-destructive weapons or for any other weapons or life threatening applications, as well as in any other life critical applications such as medical equipment, transportation, aerospace and nuclear instruments, undersea equipment, power plant equipment, disaster prevention and crime prevention equipment.

©2017—2023 TDK-InvenSense. All rights reserved. TDK-InvenSense, MotionTracking, MotionProcessing, MotionProcessor, MotionFusion, MotionApps, DMP, AAR, and the TDK-InvenSense logo are trademarks of TDK-InvenSense, Inc. The TDK logo is a trademark of TDK Corporation. Other company and product names may be trademarks of the respective companies with which they are associated.

©2017--2023 TDK-InvenSense. All rights reserved.