IAM-20680xx Accel and Gyro Self-Test Implementation

1 PURPOSE

This document explains the gyroscope and accelerometer Self-Test implementation for the IAM-20680xx 6-axis products family. Refer to datasheet for register definition and addresses.

CONTENTS

2 SELF-TEST OVERVIEW

Gyroscope and accelerometer Self-Test procedure enable customers to perform a functional test of the mechanical and electrical integrity of 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 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, in order to maintain accuracy during the accelerometer Self-Test, changes in both linear velocity and in 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 back 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)
- Gyro and Accel Fullscale Ranges (0x1B, 0x1C)

3.2 SELF-TEST SETTINGS

Accelerometer and Gyroscope must both be in Low Noise mode:

- Set PWR_MGMT_2 register, address 0x1C to 0x00 (to enable acelerometer 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

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

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

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

Accelerometer: 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 acelerometer low noise mode and select clock source then wait for 20 msec

3.3 SELF-TEST DATA COLLECTION

User can select to read Data from FIFO or registers, data are read at 1 KHz, 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 from 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 acelerometer 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 retrive the number of bytes in FIFO
   - Read FIFO by reading FIFO READ WRITE register (address 0x74) for number of bytes in FIFO
2. For registers 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 above readings 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 acelerometer 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 Configuration Save/Restore section above for additional configuration restore.

3.4 SELF-TEST PASS/FAIL CRITERIA

ST_Code is a value that is calculated from actual Self-Test measurement in 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 in order to assess self-test procedure result:

1. Retrieve factory Self-Test code (ST_Code) from above registers 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 selected full-scale value:

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

   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

4 REVISION HISTORY

Date	Revision	Description
02/07/2017	1.0	Initial release (uncontrolled AN-000xxx IAM-20680 Self Test Draft)
06/17/2020	2.0	Complete re-write to correct errors

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