Freescale Semiconductor
Application Note

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Offset Calibration of the MMA8450Q

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1.0 Introduction

Various sources of error in an accelerometer need to be understood and, in some cases, compensated before use. Understanding these sources of errors can be as important as understanding how the accelerometer operates within an application. One of the leading sources of error in an accelerometer is attributed to the 0g-offset or bias error, which is defined as: *"the difference between the measured value of the sensor from the true zero value"*.

Accelerometers are "trimmed" for offset and sensitivity in the factory by adjusting the offset trim codes and gain by using factory programmable registers within the part. Accelerometers are trimmed within a narrow test target in the manufacturing process to calibrate out these sources of error within the devices. Ultimately, the accuracy of the test station and its ability to calibrate determine how well the devices are initially calibrated during the manufacturing process.

End users then solder the accelerometers onto a PCB upon which various mechanical strains are produced: Examples:

- On the package from mounting the part to the PCB
- From the PCB mount holes or screws
- From other components placed close to the sensor

Such conditions can cause further offset or shifts. Other sources of shifts can also occur due to temperature changes and aging. All of these sources of errors may cause the accelerometer to appear to be tilted or rotated relative to the zero reference point. Re-calibration after the sensor has been PCB-mounted may be needed for other reasons as well. For example, an application may need to change the zero (0) reference point if the zero (0) position in a tilt application is always at a 15-degree angle, thus considering this the new "zero" position. These re-calibrations add to the end product manufacturing cost (by adding additional steps to assembly). Accordingly, the benefit of re-calibration will have to be weighed against these added costs.

TABLE OF CONTENTS

1.1 Key Words

Accelerometer, Calibration, 0g-offset, Bias Error, Trim, Offset Trim, Sensor, Sensitivity, Zero Reference Point, Tilt Application, AN3447, XYZ Registers, LSB.

1.2 Summary

A. The 0g offset and sensitivity errors can be significant sources of error for applications requiring high accuracy. Due to these potential sources of errors, attention and care should be taken to calibrate the MMA8450Q.

B. The calibration values will be stored in the device until the power is removed (requiring the calibration process to be performed every time the device is powered up).

C. The trade-off of the cost of this extra manufacturing step should be considered depending on the application requirements.

D. For applications requiring low accuracy tilt, or applications interested in AC measurements only, calibration may not be necessary.

2.0 MMA8450Q Consumer 3-axis Accelerometer 3 x 3 x 1 mm

The MMA8450Q has a selectable dynamic range of ±2g, ±4g and ±8g with sensitivities of 1024 counts/g, 512 counts/g and 256 counts/g respectively. The device offers either 8-bit or 12-bit XYZ output data for algorithm development. The chip shot and pinout are shown in Figure 1.

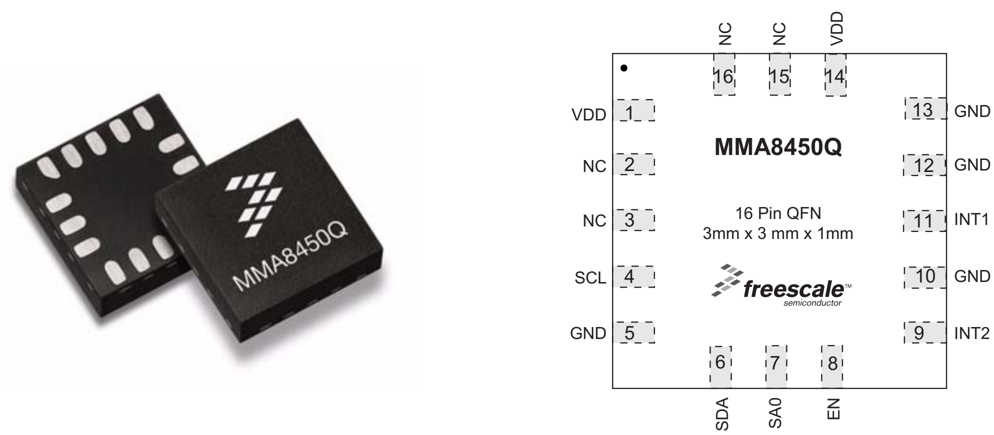


Figure 1. MMA8450Q Consumer 3-axis Accelerometer 3 x 3 x 1 mm

2.1 Key Features of the MMA8450Q

1. Shutdown Mode: Typical < 1 µA, Standby Mode 3 µA
2. Low Power Mode current consumption ranges from 27 µA (1.56 - 50 Hz) to 120 µA (400 Hz)
3. Normal Mode current consumption ranges from 42 µA (1.56 - 50 Hz) to 225 µA (400 Hz)
4. I^2C digital output interface (operates up to 400 kHz Fast Mode)
5. 12-bit and 8-bit data output, 8-bit high pass filtered data output
6. Post Board Mount Offset < ±50 mg typical
7. Self Test X, Y and Z axes

2.2 Two (2) Programmable Interrupt Pins for 8 Interrupt Sources

1. Embedded 4 channels of motion detection
   a. Freefall or Motion detection: 2 channels
   b. Tap detection: 1 channel
   c. Transient detection: 1 channel
2. Embedded orientation (Portrait/Landscape) detection with hysteresis compensation
3. Embedded automatic ODR change for auto-wake-up and return-to-sleep
4. Embedded 32 sample FIFO
5. Data Ready Interrupt

2.3 Application Notes for the MMA8450Q

The following is a list of Freescale Application Notes written for the MMA8450Q:

- **AN3915**, *Embedded Orientation Detection Using the MMA8450Q*
- **AN3916**, ***Offset Calibration of the MMA8450Q***
- **AN3917**, *Motion and Freefall Detection Using the MMA8450Q*
- **AN3918**, *High Pass Filtered Data and Transient Detection Using the MMA8450Q*
- **AN3919**, *MMA8450Q Single/Double and Directional Tap Detection*
- **AN3920**, *Using the 32 Sample First In First Out (FIFO) in the MMA8450Q*
- **AN3921**, *Low Power Modes and Auto-Wake/Sleep Using the MMA8450Q*
- **AN3922**, *Data Manipulation and Basic Settings of the MMA8450Q*
- **AN3923**, *MMA8450Q Design Checklist and Board Mounting Guidelines*

3.0 Methods of Calibrating

A few different methods of calibrating the accelerometer are discussed in AN3447, which may be helpful to review. Typically, either an end user wants to do a quick calibration with minimal amount of effort to correct the bias error, or, alternately, wants to put in more care to account for both bias and sensitivity errors in order to calibrate out these sources of error for the most accurate reading. These two methods are presented in the following.

3.1 Simple Offset Calibration Method

With no offset error, and when in the ideal zero (0) reference position, the accelerometer will read 0g. Regarding the sensor, it is important to understand what the (zero) 0g reading represents. Since the MMA8450Q is a digital part, the 0g reading will depend on how the output has been scaled. First, it is important to understand how to read the output values from the accelerometer. That is,

- In the MMA8450Q, the digital 0g reading will be 0x00
- Negative values are in 2's complement format coming out of the XYZ registers. Therefore, a value of 4095 corresponds to -1 counts as a 12 digit number

Typical procedure:

- Set the accelerometer in the flat position.
- Record the value for X and Y at 0g and Z at +1g
- Per the known device sensitivity, calculate the 0g value for Z by subtracting the 1g acceleration output from the known sensitivity

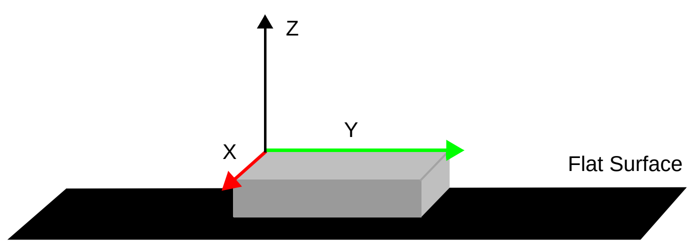


Figure 2. Accelerometer Calibration Set-up

3.1.1 Computing Calibrated Values

This technique requires the values to be read while the device is in one position, therefore, requiring minimal effort. The calibrated values are computed as follows:

$$Calx = -1 \cdot ax$$

$$Caly = -1 \cdot ay$$

$$Calz = S - az$$

where ax, ay and az are the 0g offset acceleration readings measured on the x, y and z axes, respectively.

Note: "S" refers to the sensitivity of the device.

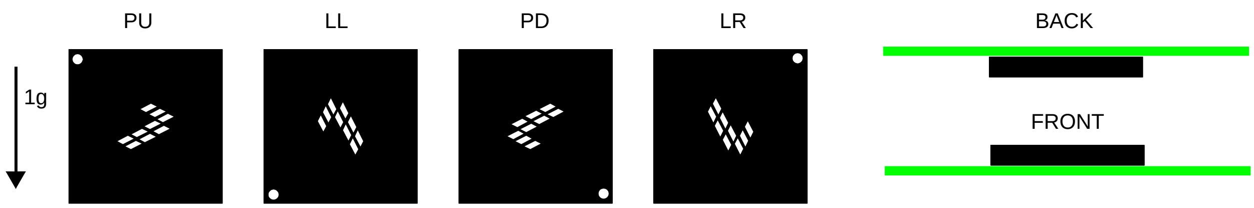
The calibrated values are added to the current acceleration reading in the device.

$$X = Current\ ax + CalX$$
$$Y = Current\ ay + CalY$$
$$Z = Current\ az + CalZ$$

3.2 More Accurate Calibration Method: Offset and Sensitivity

To increase accuracy, more characterization of the part must be performed in all six positions in order to calibrate out both the offset and the sensitivity errors. Note the following procedure.

1. Place the accelerometer on a flat surface.
2. Record the offset values for all directions of the sensor by recording the offset on all 6 faces.
3. After recording offset values for all six positions, determine the sensitivities and offsets for each axis.
4. Calculate offsets by taking the average of all four (4) 0g positions (Figure 3) or,
5. Take the midpoint reading of the -1g and +1g reading for each axis (as indicated in AN3447)



6 Positions	Portrait Up	Landscape Left	Portrait Down	Landscape Right	Front	Back
X	0g	-1g	0g	+1g	0g	0g
Y	-1g	0g	+1g	0g	0g	0g
Z	0g	0g	0g	0g	+1g	-1g

Figure 3. Offset Values on All Six Faces

The following are the sensitivity calculations for each axis:

$$S_X = \frac{(LR_X - LL_X)}{2}$$

$$S_Y = \frac{(PU_y - PU_y)}{2}$$

$$S_Z = \frac{(Front_Z - Back_Z)}{2}$$

The following are the offset calculations for each axis:

$$0g_X = \frac{(PU_X + PD_X + Front_X + Back_X)}{4}$$

$$0g_y = \frac{(LL_y + LR_y + Front_y + Back_y)}{4}$$

$$0g_Z = \frac{(PU_Z + LL_Z + PD_Z + LR_Z)}{4}$$

The calibration values are recorded as follows:

$$CalX = -0gX$$
$$CalY = -0gY$$
$$CalZ = -0gZ$$

4.0 Calibration Procedure for the MMA8450Q

In the MMA8450Q there are three 8-bit (volatile) offset registers for storing the calibration values, at one register per axis. When the offsets are stored in these registers the values will be added to the X, Y, and Z output of the device automatically until the device is powered off. When the device is powered off, these values will be lost. Note: In order to avoid re-programming for offset, store the calibration values in memory on the processor or MCU. There are three (3) sensitivity ranges that are possible for reading the output acceleration.

1. The 2g mode is 1024 counts/g or (1mg/count)
2. The 4g mode is 512 counts per g or (2mg/count).
3. The 8g is 256 counts per g or (3.9mg/count).

Calibration is made easier by switching between Standby mode and 8g Active mode because one (1) calibration count corresponds to one (1) LSB on the output. Therefore, no multiplication is required.

- 1 count calibration = 1LSB in 8g mode
- 1 count calibration = 2LSB in 4g mode
- 1 count calibration = 4LSB in 2g mode

4.1 Calibration from 2g Mode

If the calibration is done reading in 2g mode (1mg/count) then for every output value it will be necessary to divide that number by 4 when storing it in the calibration register. Fractional values cannot be stored. For example, if the offset for the X-axis (which is intended to be at 0 counts) result is 21 counts in 2g mode, then 2¼ = +5.25. The value to be stored to ensure the X-axis will be at 0 counts will be -5. This will correspond to 251 in the register since the calibration register uses 2's complement math.

4.2 Calibration from 4g Mode

If the calibration is done reading in 4g mode (2.0mg/count) then every value will be divided by 2 when storing it in the calibration registers. For example if the offset result is 9 counts for the same example from the output in 4g mode the 9/2 = 4.5. The value to be stored is either -4 or -5.

4.3 Calibration from 8g Mode

The simplest method is to read the data in 8g mode (3.9mg/count). The value stored in calibration will not require division. If the offset result is 5 counts in 8g mode for the X-axis, intended to be at 0 counts, then 5/1 = +5. The value to be stored in the calibration registers is -5.

Advisory: It is best to read the data at 1.56 Hz Output Data Rate (ODR) to avoid noise when performing the calibration. This is the highest resolution sample rate with over 10 effective bits. When calibrating manually, it may be necessary to go through this process more than once to completely zero the offset to within ±4mg (1LSB in 8g mode).

5.0 Auto-Calibration Example Procedure

In the following example routine, the board will remain flat and will take readings in 8g mode, where X would ideally read 0 counts, Y would read 0 counts, and Z would be at 256 counts. The device goes into 8g active mode to read out the new XYZ values and then goes into standby mode to write the updated calibration values.

Note: Hold the board flat so that X and Y are in the 0g field and Z is in the 1g field.

- Xcal = 0; //Initialize the calibration values to zero
- Ycal = 0;
- Zcal = 0;

```
for (int i = 0; i < 2; i++) // Iterate twice for accuracy
{
      Step 1: Put the Device into 8g Active Mode and set the sample rate to 1.56Hz
            gMode[0] = 8g_ActiveMode; // 8g mode
            dRate[0] = ODR1_56; //Set ODR to 1.56Hz

            MMA8450QDriverObj.SetDataRate(dRate);
            MMA8450QDriverObj.SetFS(gMode);
            Thread.Sleep(2000); // Wait 2 seconds to collect reading

      Step 2: Read Out the 12 bit Data from the Registers
            byte[] XYZ12 = MMA8450QDriverObj.ReadXYZ12();
            XdataL = XYZ12[2];
            XdataH = XYZ12[3];
            Xdata = (short)(XdataH * 16 + XdataL);
            YdataL = XYZ12[4];
            YdataH = XYZ12[5];
            Ydata = (short)(YdataH * 16 + YdataL);
            ZdataL = XYZ12[6];
            ZdataH = XYZ12[7];
            Zdata = (short)(ZdataH * 16 + ZdataL);
      Step 3: Calculate Out the Calibration Values Based on the Current Data
            if (Xdata > 2047)
            {
            Xdata = (short)(Xdata - 4096);
            }
            if (Ydata > 2047)
            {
            Ydata = (short)(Ydata - 4096);
            }
            if (Zdata > 2047)
            {
            Zdata = (short)(Zdata - 4096);
            }
            Xcal += -1 * Xdata;
            Ycal += -1 * Ydata;
            Zcal += (256 - Zdata);

      Step 4: Put the Device into Standby Mode
            gMode[0] = 0;
            MMA8450QDriverObj.SetFS(gMode);
            int[] cal = new int[3];
            cal[0] = (int)Xcal;
            cal[1] = (int)Ycal;
            cal[2] = (int)Zcal;
      Step 5: Write Calibration Values to the Calibration Registers
            MMA8450QDriverObj.SetCalValues(cal);

            } // End of loop
```

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