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Application Note

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Implementing Auto-Zero Calibration Technique for Accelerometers

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INTRODUCTION

This application note describes why it is important to implement an auto-zero calibration function into the MMA73x0L series accelerometers and how to implement it with a microcontroller containing an analog-to-digital converter. This auto-zero compensation technique is based on sampling the accelerometer voltage output value at 0g which is the zero reference. This reference value is known as the offset voltage. The expected offset values for the MMA73x0L series accelerometers is listed in Table 1 for 0g, +1g.

Table 1. Offset Values for MMA73x0L for X, Y and Z Directions

Device	Sensitivity	0g	-1g	+1g
MMA7360L	800mV/g	1.65V	0.85V	2.45V
MMA7340L	440mV/g	1.65V	1.21V	2.09V
MMA7330L	308mV/g	1.40V	1.092V	1.708V

OFFSET ERRORS AND WHY AUTO ZERO CALIBRATION IS IMPORTANT

Sources of offset errors can occur device to device based on offset variations from trim errors, mechanical stresses from the package and mounting, shifts due to temperature and due to aging. These variables can all change the offset. This can be very significant for many applications. The offset error alone can affect a tilt reading on a flat surface by as much as 12 degrees. That is an unacceptable error for this application.

Performing an auto-zero calibration technique using a microcontroller with an A/D converter can reduce these errors, but note that the error correction will be limited by the resolution of the A/D converter.

Figure 1 illustrates the transfer function of the accelerometer. This relation assumes linearity. The output is a voltage and the input is the acceleration measured in g's. The equation of the line is expressed as follows:

$$V_{OUT} = [(V_2 - V_1)/(g_2 - g_1)]*g + V_{OFF} = S*g + V_{OFF};$$

where V_2 and V_1 are two voltages and g_2 and g_1 are their corresponding input acceleration values. The slope of the line $S = (V_2-V_1)/(g_2-g_1)$ is the sensitivity of the accelerometer sensor. The y-intercept of the line is the voltage offset value V_{OFF}.

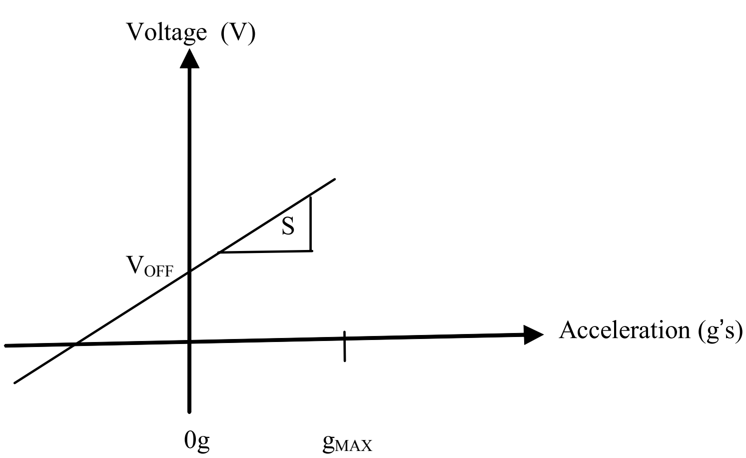

Figure 1. Transfer Function of the Accelerometer Sensor

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A two point acceleration calibration can be performed to accurately determine the sensitivity and get rid of the offset calibration errors. This can be very expensive in high volume production due to extra time involved. Therefore, the sensitivity and offset data is given in the data sheet and a linear equation is used to determine the acceleration.

$$\text{Acceleration}(g) = (V_{OUT} - V_{OFF})/S$$

If an offset error is introduced due to device-to-device variation, mechanical stresses or offset shift due to temperature, those errors will show up as an error in the acceleration reading. As shown in Figure 2, if an offset error is introduced (ΔV_{OFF}) then there will be a corresponding error in the acceleration reading, Δg.

$$g + \Delta g = [V_{OUT} - (V_{OFF} + \Delta V_{OFF})]/S$$

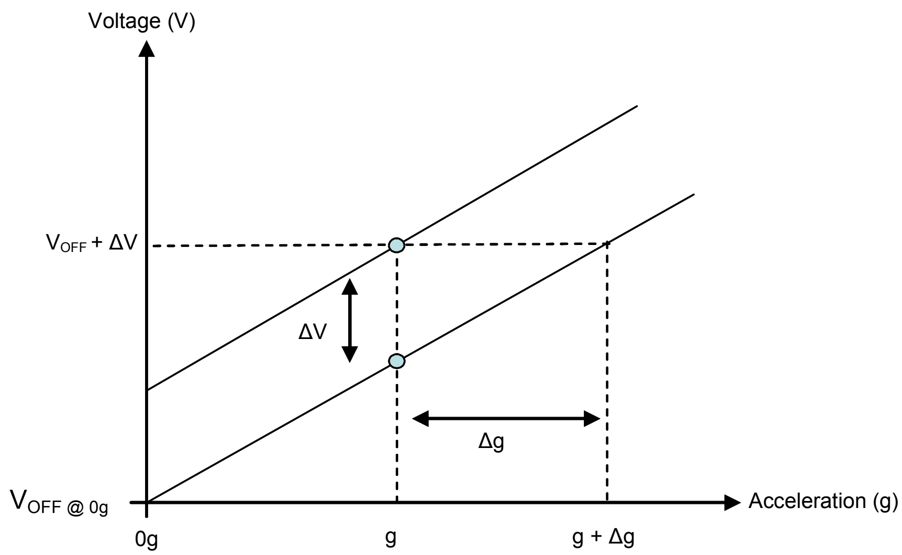

Figure 2. Effects of Offset Errors

OFFSET CALIBRATION ERRORS

The minimum expected and maximum offset values at 0g for the MMA73x0L devices are listed in Table 2.

Table 2. Offset Value Range for the MMA73XOL Accelerometer Series

Device Name	g-Range	Min. Offset	Expected Offset	Max. Offset
MMA7360L	1.5/6	1.485V	1.65V	1.815V
MMA7340L	3/12	1.485V	1.65V	1.815V
MMA7330L	4/16	1.316V	1.4V	1.484V

Even though the offset is laser trimmed, offset can shift due to packaging stresses, aging and external mechanical stresses due to mounting and orientation. This results in offset calibration error. Table 2 lists the minimum, maximum and expected offset ranges.

TEMPERATURE COEFFICIENT OF OFFSET ERRORS

The offset error due to temperature is due to the Temperature Coefficient of Offset (TCO). This parameter is the rate of change of the offset when the sensor is subject to temperature. It is defined as: TCO = ($\Delta V_{OFF}/\Delta T$) assuming it is linear. The MMA7360 has a TCO normalized with the span at 25°C of ±0.03% / °C.

TECHNIQUES FOR CALIBRATING THE OFFSET VOLTAGE

Manual 0g X, Y, Z Full Range Calibration

In order to find the 0g voltage output value of the accelerometer it is necessary to know that the device is sitting completely level. Although placing the device on the table may seem flat, this doesn't guarantee that the device is not experiencing a slight g force. The device may be experiencing more that 0g due to packaging or device shifts. One method used to get an accurate and reliable 0g reading is to rotate the device from +1g through -1g. The max value will be +1g and the minimum value will be -1g. Assuming that the sensitivity is symmetric from zero to positive and from zero to negative the sensitivity of the device can be calculated by dividing by 2. Knowing the sensitivity the 0g offset value can be calculated by adding the sensitivity to the minimum value or by subtracting the sensitivity from the max value. It is also a good idea to place the part level and check the 0g offset value. It should be very close. This method must be followed for all three axes. The drawback of this technique is that it is tedious.

Simple 0g X, Y, Z calibration

Another method would be to assume 0g on a level surface. The device would need to be turned 90 degrees once to go from 0g XY to 0g in Z. The 0g values would be recorded this way. This technique does not guarantee as much accuracy as the previous method.

Freefall Calibration

Another method to calibrate the device for 0g offset would be to record the offset of X, Y and Z while the device is in freefall. The possible downfall of this approach is the fact that the device may rotate while falling and put a force on the device. Also it may be inconvenient to recalibrate each time by putting the device in freefall. The benefit of this approach is that all three axes can be at 0g all at the same time.

Simple 0g X, 0g Y, +1g Z calibration

Another method that is extremely convenient would be to place the device on a flat surface so that X is at 0g, Y is at 0g and Z is at +1g. The values are recorded. The X and Y offset values would be fairly accurate, but the +1g value would have errors because this value would not be recorded at 0g. The known sensitivity would be subtracted from the +1g to calculate an assumed 0g offset value for Z. This is convenient in that the device would never need to be rotated or moved. The disadvantage of this approach is that it is the least accurate way to calibrate 0g offset of the above mentioned techniques.

IMPLEMENTATION OF AUTO-ZERO WITH A MICROCONTROLLER

When implementing auto-zero (a zero reference) 0g must be used. An auto-zero command can be automated by the system or it can be commanded manually. This may be somewhat dependant on the application. Note that if the auto-zero is to be performed only once and the offset correction data is stored in memory the TCO offset error and calibration error will not be corrected if the sensor later experiences a wide temperature range or later experiences an offset shift. It would be wise to perform an auto-zero calibration at the operating temperature to compensate for the TCO and auto calibrate as often as possible to dynamically compensate for system offset errors.

Auto-zero can be implemented easily when the integrated sensor is interfaced to a microcontroller. The auto-zero algorithm is listed below:

1. Sample the sensor output when a known zero reference is applied to the sensor (0g is the reference). Store the current 0g or +1g offset (depending on the technique used) as CZ_{OFF}.
2. Sample the sensor output at the current applied acceleration. Call this CA.
3. Subtract the stored offset correction, CZ_{OFF}, from CA. The acceleration being measured at the current reading is simply:

$$A_{MEAS} = [CA - CZ_{OFF}]/S$$

For the *Simple 0g X, 0g Y, +1g Z calibration* technique a slightly different calculation is required for the Z axis which has recorded the CZ_{OFF} value at +1g. The sensitivity ‘S’ must therefore be subtracted from CZ_{OFF} in the calculation.

For the Z Case:

$$A_{MEAS} = [CA - (CZ_{OFF} - S)]/S$$

Note that the equation is simply a straight line equation where S is the sensitivity of the accelerometer. The auto-zero algorithm is shown graphically in Figure 3.

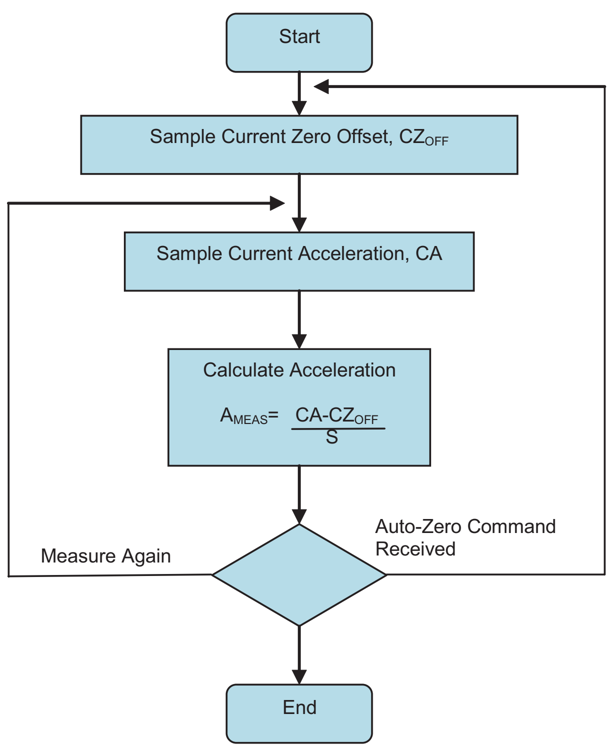

Figure 3. Flow Chart of the Auto-Zero Algorithm

Sample Code for: *Simple 0g X, 0g Y, +1g Z calibration method*

S = Sensitivity;

X0g_current = XCZ_{OFF};

Y0g_current = YCZ_{OFF};

Z1g_current = ZCZ_{OFF};

XCA = XCA_val;

YCA = YCA_val;

ZCA = ZCA_val;

AmeasX = (XCA-X0gcurrent)/S;

AmeasY = (YCA-Y0gcurrent)/S;

AmeasZ = (ZCA-(Z1g_current-S))/S;

Sample Code for: *all other 0g calibration methods*

S = Sensitivity;

X0g_current = XCZ_{OFF};

Y0g_current = YCZ_{OFF};

Z0g_current = ZCZ_{OFF};

XCA = XCA_val;

YCA = YCA_val;

ZCA = ZCA_val;

AmeasX = (XCA-X0gcurrent)/S;

AmeasY = (YCA-Y0gcurrent)/S;

AmeasZ = (ZCA-Z0g_current)/S;

A/D RESOLUTION ERROR

The auto-zero calibration technique can reduce the offset errors, but the A/D converter used in this process has a limited resolution and therefore introduces an error of its own.

Typically an 8 bit A/D converter is used, which cuts the 3.3V supply voltage on the MMA7360L into 255 steps, 12.9mV for each step. If a 10 bit A/D converter is used this would cut the 3.3V supply voltage into 1023 steps, 3.2mV for each step. A 12 bit A/D converter cuts the 3.3V supply voltage by 4095 steps, 0.8mV per step. Therefore the resolution is much better when a larger A/D converter is used, which reduces the error. Using an 8 bit A/D converter the voltage offset would be V_{OFF} + 0.129V = 1.779V. The V_{OFF} can be auto-zeroed, but the A/D converter resolution remains erroneous.

CONCLUSION

An auto-zero calibration technique is very important for minimizing offset errors. It is easily implemented into the accelerometer sensor system using a microcontroller with an A/D converter and a few lines of code. The resulting minimized offset errors of the system is limited only by the resolution of the A/D converter.

REFERENCES

1. AN1636, Implementing Auto Zero for Integrated Pressure Sensors, Ador Reodique, Freescale Semiconductor, Inc., Freescale Application Note.

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