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Measuring Freefall using Freescale's MMA7360L 3-Axis Accelerometer

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INTRODUCTION

This is an article which describes the use of Freescale's MMA7360L 3-axis accelerometer as a freefall detection sensor. This is also a discussion of different types of freefall scenarios, the detection method using the MMA7360L accelerometer, and the limitations of the linear freefall detection. The MMA7360L can detect freefall which can be used as a device protection mechanism. A well known example of this is for disk drive head protection. Damaging freefall events can happen very quickly. Freefall must be detected by the accelerometer and the disk drive must be signaled to park the drive into safety all within an extremely short window of time. The challenge is to accomplish this algorithm within this short time period of a fraction of a second. A robust freefall algorithm should be able to sense various different types of freefall scenarios.

FREEFALL SENSING

A 3-axis accelerometer offers a more accurate result when monitoring for freefall than a 2-axis accelerometer. In a 2-axis solution, when horizontally oriented, the X-axis and Y-axis outputs are the same (0g) regardless of whether the accelerometer is stationary or falling. When a 3-axis accelerometer is stationary, the total magnitude of the acceleration on the sensor is equal to 1g = - 9.8 m/s^2, at any orientation.

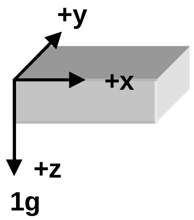

Figure 1. Example of a 3-axis Accelerometer

When the sensor is in freefall, assuming a linear freefall with no initial acceleration or angular acceleration, the output acceleration will approach 0g. The distance of the fall and the time of the freefall can be calculated from known equations of motion. If there is an angular acceleration on the sensor as it is falling the output of the accelerometer can be quite high. There are limitations of the linear freefall that must be understood, some of which can be compensated for using different algorithms and additional circuitry.

MMA7360L ACCELEROMETER

The MMA7360L is a low power, low profile capacitive micromachined accelerometer featuring signal conditioning, a single pole low pass filter, temperature compensation, self test, 0g detect which detects linear freefall, and g-Select which allows for the selection among 2 sensitivities. The zero-g offset and sensitivity are factory set and require no external devices. There is also a sleep mode pin on the accelerometer which makes it ideal for handheld battery powered electronics.

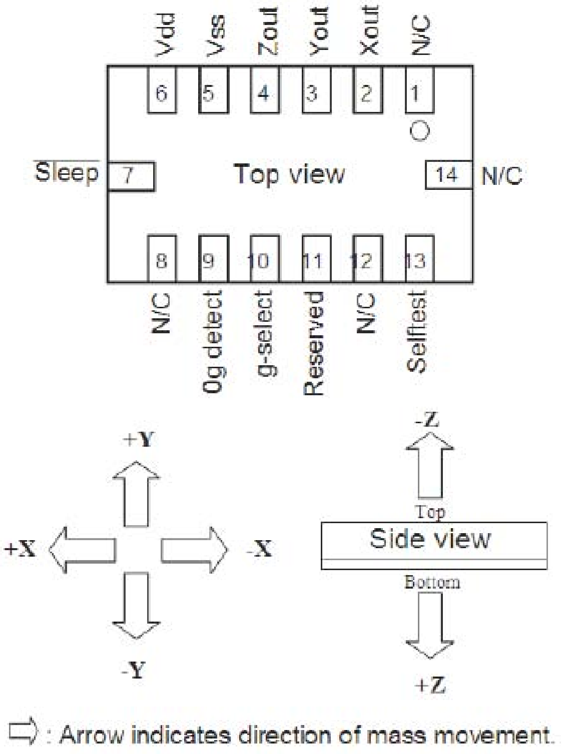

Figure 2. Pin Out of MMA7360L

PIN OUT OF MMA7360L

Pin 9 on the MMA7360L is the 0g detect digital logic output pin. In the 0g detect circuit there is a window comparator, latch, and other control logic circuitry. When the output is in the equivalent voltage range of -0.4g to +0.4g the comparator output goes to a digital logic high and is latched. Each output applied to the window comparator is multiplexed. When the 3 latch outputs are high at same time, the 0g detect output, pin 9, goes high. It will be kept high until one of the outputs goes out of the range of -0.4g to +0.4g. Note: This threshold range is for the MMA7360L device.

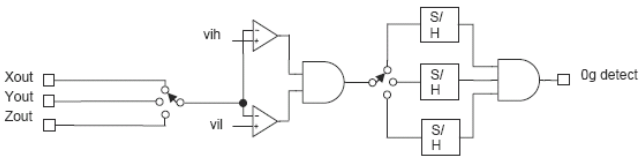

Figure 3. 0g Detect Circuitry in the MMA7360L for Pin 9

EQUATIONS OF MOTION

The following are the equations of motion for the case of constant acceleration. By integrating acceleration one can solve for velocity. Then to solve for position, a second integration is required as shown below in the following equations.

A = constant = -9.81m/s^2

(Integrate acceleration to get the velocity equation)

$$v = \int A\,dt = v_0 + At$$

(Integrate velocity to get position.)

$$d = \int (v_0 + At)dt$$

$$d = d_0 + v_0 t + At^2$$

$d = \frac{1}{2}At^2$, solving for time: $t = \sqrt{\frac{2d}{A}}$

(Assuming the initial conditions are equal to zero)

Table 1. Calculated Time and Distance for a Linear Fall

Time	Distance
1ms	4.91µm
10ms	0.49mm
100ms	4.91cm
500ms	1.23m
1s	4.91m
5s	122.63m
10s	490.5m

Distance	Time
1cm	45ms
10cm	142ms
1m	451ms
5m	1s
50m	3.19s
100m	4.52s
500m	10.1s

Based onTable 1 one can determine the time that a fall will take based on the distance or visa versa. When designing a freefall protection algorithm the typical height of the fall or a range of heights should be considered. Then the time the system will take to realize the device is in freefall, along with the time required to implement a protection mechanism, must be considered. For example it may take 10 ms to realize that a freefall is occurring, and then it takes typically 60ms to park a disk drive head.

LIMITATIONS OF LINEAR FREEFALL DETECTION FOR MMA7360L

0g Offset Shifts

0g offset errors occur device to device based on offset variations from trim errors, mechanical stresses, from the package mounting, shifts due to temperature and due to aging. All of these variables can change the 0g offset value which ultimately will affect the ability for the 0g detect to function within the full +0.4g to -0.4g range. There is no way to internally compensate for 0g offset errors. The only way to resolve this problem would be to use an A/D converter on a microcontroller, sample the x, y and z outputs and run a 0g calibration routine.[1]

Freefall Detection Errors from Shaking or Possible Noise

It is possible that the accelerometer could have forces acting on it from shaking or certain motions which would set off the 0g detect pin by measuring in the detection range. This would cause a false freefall detect. This is depicted below in Figure 4 in the left callout bubble. Shaking or noise can cause the 0g detect pin to spike to V_{dd} (indicating a false freefall). In order to overcome this error one could add a single pole RC filter on the output of this pin. This filter will help reduce noise. The bandwidth of the filter is chosen based on the largest time constant delay that is acceptable for the application. Based on Table 1 one can determine from a known distance the time required. The time that the system takes to realize that the device is in linear freefall and the time required to implement a freefall mechanism must be considered. For example if the application is for a linear freefall distance of approximately 30cm or greater then the time for the object to move 30 cm is calculated to be 247ms. If it takes 60ms to park the disk drive head then there is a maximum of 187 ms to realize a freefall is occurring. Therefore the time response from the low-pass filter can be a maximum of 187 ms.The output of the filter is depicted in the right callout bubble. The inverter is used as a threshold detection. An inverter or a comparator could be used here. When the output is greater than ½ V_{dd} the output is detected on the New 0g detect output. This Δt value (in the right callout box) will be the time constant, which is the time delay estimate from the filter to reach ½ V_{dd}.   Another solution to this problem is to use a microcontroller with the accelerometer. This is discussed in the next section “Detecting Freefall using a Microcontroller”.

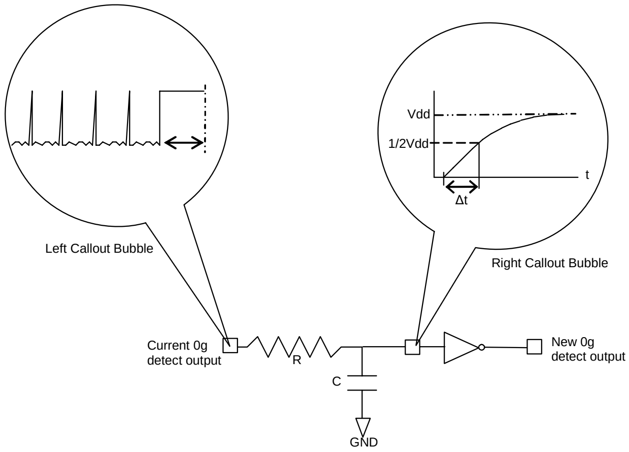

Figure 4. 0g Detect Modified Circuit Output

Projectile and Rotational Falls

If the device is thrown upward it will be in freefall in the “0g” condition when the device is still moving upward, which lengthens the freefall time. Similarly if the device is thrown downward this will shorten the time the object takes to detect freefall before hitting the ground.

Centripetal acceleration will be present if the object rotates while falling. If the accelerometer is not mounted in the very center of the device it will experience centripetal acceleration if rotating while falling. When this occurs the output will be greater than the threshold limit and therefore freefall will not be detected from the linear 0g detect pin. In order to account for this type of a freefall condition a more advanced algorithm would be required using a microcontroller to monitor the X, Y and Z outputs to determine the characteristic behavior before and during the rotational and/or projectile fall.

DETECTING FREEFALL USING A MICROCONTROLLER

There are additional reliability benefits using a microcontroller with the MMA7360L accelerometer, but the trade off is the additional cost required, and extra time delay to detect the freefall condition. This section will discuss the benefits and additional flexibility of using a microcontroller.

When using a microcontroller the outputs of the X, Y and Z can be read and the 0g offset can be calibrated so that it is zeroed out. This is described in full detail in AN3447. The 0g offset calibration can be programmed, then the magnitude of the total acceleration can be calculated for the X, Y and Z outputs in the equation below. This is a slightly more accurate method than simply using pin 9 for the 0g detect because there is no 0g offset calibration when measuring straight off pin 9.

Magnitude of Total Acceleration When Static:

$$A = \sqrt{A_X^2 + A_Y^2 + A_Z^2} = 1g$$

using the Pythagorean theorem

Linear Freefall Using a Microcontroller

Using the X, Y, Z Filtered Outputs With the Microcontroller

When the total acceleration, A is between the threshold range of -0.4g to +0.4g a linear freefall event will be detected. This threshold range can now easily be changed in software. Depending on the application a tighter threshold might be required. Also using a microcontroller it is easier to filter out false positive events caused by shaking or noise. When the total acceleration is approximately 0g (or within a predefined threshold) for a predefined duration of time (5-10 bits in a row) a linear freefall event is detected. Sampling multiple times to check and verify the event will increase the detection time, but this increases the reliability of the algorithm.

Using the 0g Detect Pin with the Microcontroller

If using the 0g detect pin to detect linear freefall, a microcontroller can be used to sample the output for a predefined period of time (5 to 10 events in a row) to verify the cause is a freefall and not false positives from shaking or noise.

The time that it takes to detect freefall is related to the sampling rate of the A/D converter in the microcontroller used, and also the number of samples used to verify that the event has occurred. Table 2 displays various sample rates and the number of samples used before detecting an event.

Table 2. Sampling Frequency and Freefall Detection Times

Sampling Frequency	No. of Samples Used	Time to Detect (ms)
50	**1**	**20**
100	**1**	**10**
200	**1**	**5**
500	**1**	**2**
50	5	100
100	5	50
200	5	25
500	5	10
50	10	200
100	10	100
200	10	50
500	10	20

One should compare the values in Table 2 to those in Table 1 and be sure to use a sampling frequency that does not compromise the accuracy to detect a freefall event (using more than 1 sample) or the fall time required for the application to implement a protection mechanism.

Rotational and Projectile Type Fall Conditions

A rotational fall is defined as a fall event where the device is spinning (rotating) during the fall. There is centripetal acceleration acting on the device which will give accelerometer output readings which are out of the linear freefall 0g detect threshold. A projectile freefall is defined as a freefall that occurs with a linear acceleration on it in X, Y or Z or on a combination of the three axes. Again this would put the accelerometer out of the 0g detect threshold for linear freefall. In the projectile fall case the initial velocity and acceleration is not zero. Note also that a projectile rotational fall is also another possible type to consider which includes both the centripetal acceleration and additional linear acceleration during the fall. These fall conditions can be detected by using more involved algorithms which monitor the acceleration events that occur on the X, Y and Z axis right before the fall event and during the fall event.

Some considerations for developing this algorithm include the following:

1. Max and Min typical acceleration values during use of the device for X, Y, Z
2. The typical time that the device dwells in certain acceleration ranges.
3. The absolute maximum allowable acceleration on the device.

It is necessary to understand the characteristic acceleration behavior of the application to differentiate what is a typical use of the device and what is an uncontrolled use or potential dangerous falling event. It is key to analyze, differentiate and monitor readings over time. These algorithms will take longer to signal the event of freefall than the simple 0g detect linear freefall event. Below is an example output of a linear freefall and a rotational freefall. Note that in the linear freefall case all outputs converge to near 0g, whereas during the rotational freefall the magnitude of the total acceleration is much greater than 0g.

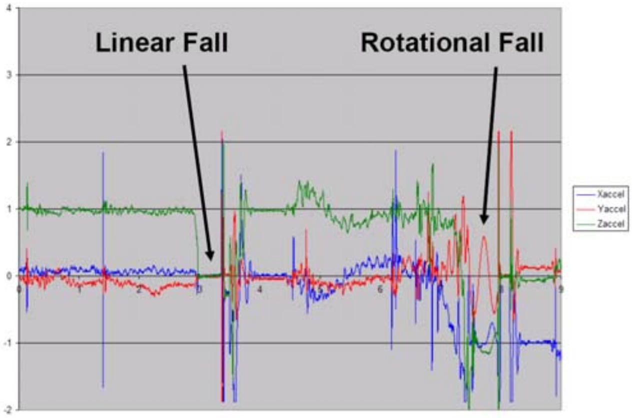

Figure 5. Graphical Display of a Linear Freefall and a Rotational Fall Event

CONCLUSION

The MMA7360L 3-axis accelerometer provides very useful freefall detection sensing. The linear freefall sensing output pin is a low cost solution for measuring linear freefall. For a more robust freefall solution the MMA7360L can be used with a microcontroller to detect various different types of fall scenarios including rotational and projectile falls. Damaging freefall events can happen in less than a second. It is key to keep in mind the timing to detect and protect an object from a fall.

RELATED ARTICLES

[1] AN3151 “Detecting Freefall with Low-G Accelerometers” by Michelle Kelsey

[2] AN3447 “Implementing Auto Zero Calibration Technique for Accelerometers” by Kimberly Tuck

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